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PROBLEM-SOLVING INTERACTIONS IN THE COLLABORATIVE DISCOURSE OF ENGINEERING DESIGN: A DESCRIPTIVE FRAMEWORK AND THREE APPLICATIONS

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PROBLEM-SOLVING INTERACTIONS

IN THE

COLLABORATIVE DISCOURSE OF ENGINEERING DESIGN:

A DESCRIPTIVE FRAMEWORK AND THREE APPLICATIONS

by
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To my mother, Mary Lois Carpenter,
and to the memory of my father, Frank Marques Carpenter

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PREFACE

My interest in group problem-solving began in the late 1980s. At that time, I was a technical writer by day and a college instructor of English as a Second Language (ESL) by night. My day job required that I work closely with professional engineers, many of whom were nonnative English speakers, while in the evenings most of my ESL students were engineering majors.

One summer my company assigned me to a seven-person team that was designing a computerized records-control system for the New York City Housing Authority. The team was quite heterogeneous, including software engineers and programmers from Hong Kong, Korea, India, and Taiwan, as well as the United States. A few were recent college graduates, while others had two or three years of company experience. In terms of position in the company, however, the team members were nominally peers, and they had considerable autonomy in organizing themselves and coordinating their operations.

This assignment stands out in my memory because it was the first time that I attempted to observe, in a "scholarly" way, the use of language in a professional setting. While my primary goal in the project was of course professional, a secondary goal was pedagogical. I wanted to discover for myself whether there were patterns of discourse among problem-solving engineers, and, if so, perhaps I could make my ESL students aware of those patterns.

My position as the technical writer for the team gave me an ideal observational platform, and I had the same prerogatives as those of an apprentice entering into a "community of practice" (Lave & Wenger, 1991; Wenger, 1998). I was an active but peripheral participant in a complex, long-term, real-world engineering design project from beginning to end. Moreover, I had free access to project information as it became available, and I could discuss issues with my coworkers and listen in on their conversations. Yet I was slightly outside the critical path of operations, so that I could observe somewhat objectively the individual and collective behaviors of the engineers working together, adapting to one another, sharing their knowledge and skills, negotiating technical and procedural points, and resolving discrepancies in views. In Erikson's words, I was a participant-observer immersed in "an ecology of social and cognitive relations in which influence between any and all parties [was] mutual, simultaneous, and continuous" (Erickson, 1996, p. 33; cited in Barron, 2000).

Gradually, as the project unfolded and as I became more deeply involved in the project, the focus of my amateur "field work" drifted from the forms of discourse that I might import to the ESL classroom to the complex relationships I began to see between the general conversation around me and actual problem solving. I became aware that much problem solving and decision making was embedded in the ordinary talk between team members. Ideas seemed to spring from conversation, ideas that the speakers jointly arrived at merely by responding to each other's spoken remarks. At times it seemed that it was the face-to-face communications that were driving the project. Moreover, in their interactions members seemed to dispose themselves toward each other and shape their conversation to optimize what they could learn and understand. There seemed to be no conscious effort to do so, but whenever a conversation became purposeful—that is, task directed—the speakers made use of conversational processes that channeled their thinking toward some form of agreement, which in turn marked a new point of departure in their work together.

I became aware that team members took turns in assuming conversational roles. For example, one would propose or explain while others would challenge or elaborate. From topic to topic, these roles shifted among the team members, but always the roles served to increase the amount of free-floating information accessible to all members. Less experienced team members took supportive and assistive roles, but, far from being mere onlookers, they raised questions, tested their understanding by repeating what they had heard, asked for explanations, and sometimes caused the more experienced engineers to trip on their own logic and to reconsider their positions. At the least, the steady patter of information-rich talk kept the whole team aware of what each was doing or going to do and how their actions might affect someone else's work.

Sometimes it was hard to separate the communicative from the cognitive. When confronted with a new idea, was an engineer fumbling for words because of an inadequate vocabulary or because of the complexity of the issue? It was also difficult to separate the thinking of the group from the thinking of the individuals, because ideas merged or rode the backs of previous ideas. In short, from what I have read since those days, I can easily see why some theorists call a problem-solving team a cognitive system (e.g., Hutchins, 2000).

In the end, the six-month project was successful, and the Authority was satisfied with its software. After a brief celebration, the team disbanded, and we moved on to different projects. In my scholarly ambitions, however, I was left with a sense that I had observed many significant conversational processes, but that I had neither the theory nor the method to understand fully what I had seen. I hoped that someday I would be able to learn more.

As it turned out, that day did come. I am now teaching and studying at another university, where I have had the opportunity to research and prepare this study on collective problem solving. As I reviewed the literature on group processes, the New York Housing Authority Project frequently came to mind; it provided many concrete examples of the types of behaviors I read about. That experience, combined with my readings, led me to see clearly that engineering problem-solving is both a cognitive and a social process—but how is one to combine those two perspectives? As Hutchins says, groups do not think in the same ways as their members (Hutchins, 2000). For the individual participating in a group, learning takes place through interactions with others within the system (Rogoff, 1998); for the group, learning is a continuous process of adaptive reorganization (Hutchins, 2000, p. 289) of relations among the individuals. To understand the cognitive properties of a group or social system, therefore, one must make reference to the cognitive properties of the individual members, and to understand the cognitive properties of the members, one must make reference the properties of the system (p. 287). For the educator whose traditional unit of analysis is the individual student, the question becomes this: How can a teacher apply theory that addresses supra-individual learning processes to classroom practices that address individual development? What lies in the theoretical space between individuals who are learning *in groups* and groups that are learning *as groups*?

Recent research in distributed cognition suggests that individual and group learning processes may not be mutually exclusive but are indeed inexorably bound. There is evidence, for instance, that the social mechanisms for individual learning have counterparts in group learning and vice versa. These social mechanisms may affect both the knowledge state of the individual and the knowledge state of the group, even though those knowledge states may not be remotely the same. To discover how those individual/group learning mechanisms operate, however, educators need some model or framework by which they can make sense of the seeming chaos of engineering discourse. They need some assurance that there are definable, classifiable ways in which problem-solving engineers interact. If they can know, that is, that some modes of cooperative behavior serve project teams more effectively than others, then educators may be able to give their students practice in the cognitive and communicative processes that empower not only the students themselves but also the groups in which the students work.

Barron, B. (2000). Achieving coordination in collaborative problem-solving groups. *The Journal of the Learning Sciences, 9*(4), 403-436.

Erickson, F. (1996). Going for the zone: The social and cognitive ecology of teacher-student interactions in classroom settings. In D. Hicks (Ed.), *Discourse, learning, and schooling* (pp. 29-62). Cambridge, MA: Cambridge University Press.

Hutchins, E. (2000). *Cognition in the wild*. Cambridge, MA: The MIT Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Rogoff, B. (1998). Cognition as a collaborative process. In W. Damon (Ed.), *Handbook of child psychology* (Vol. 2, pp. 679-744). New York: J. Wiley.

Wenger, E. (1998). Communities of practice: Learning as a social system. *Systems Thinker, 9*(5).

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The purpose of this study is to develop a framework whereby a systematic approach can be applied to the description and study of problem-solving discourse between engineers in the early definitional stages of design projects. The framework is applied to the de-

scription of discourse within three teams of student electrical and computer engineers working in two-person teams to define and plan solutions to complex design problems. The framework helps in the understanding of how certain team-member properties (differences in partner preferences for cognitive and communicative tasks) and perceptions of team and individual performance (differences in partner satisfaction with the cognitive and communicative aspects of their team project) relate to the cooperative patterns that appear in team problem-solving discourse. Questionnaires are used to obtain task-preference and project-satisfaction data for each team member and to generate profiles that highlight the differences between team members. To identify cooperative patterns, discourse analyses are performed on transcriptions of team dialogue. By taking entire teams and not merely the individuals that compose them as the units of analysis, the study provides insights into how fundamental differences between team members relate to the qualities of problem-solving discourse and how the qualities of team discourse relate to project satisfaction. Such insights may be helpful to instructors of technical-communication courses who want to incorporate problem- or project-oriented activities to their class activities and seek the conceptual tools to interpret the collaborative behaviors they observe.

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CHAPTER 1
FOUNDATIONS OF THIS STUDY

At the core of any complex engineering design project are two or more engineers talking. Explaining, negotiating, coming to terms, coordinating activities—they must continually communicate to build and maintain a common ground of knowledge and understandings (Baker, 1998; Baker, Hansen, Joiner, & Traum, 1999; Clark & Schaefer, 1987; Dillenbourg, 1999a; Hutchins, 2000; Lave & Wenger, 1991; Resnick, 1991; Resnick, Salmon, Zeitz, Wathen, & Holowchak, 1993; Roschelle & Teasley, 1991; Saloman, 1993b; Suchman, 1987). Clearly, modern design[1] is a cognitive *and* a social activity, and much may be learned about design and designers by listening in on their talk.

This study investigates the interplay of social and cognitive processes that appears in the conversation of engineering teams attempting to solve design problems together. This chapter briefly describes the study itself, its research questions, and its theoretical approach. The chapter then discusses the importance of collaboration as a topic of study in engineering and scientific problem solving. Finally, the chapter reviews theoretical re-

[1] Design is defined (from the cognitive perspective) later in this chapter and in Appendix A. For present purposes, design in engineering may be defined according to the Accreditation Board of Engineering and Technology (ABET) as follows:

> . . . the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. [Cited from the Accreditation Board of Engineering and Technology-(ABET), 1993.

Design is not a problem so much as it is a collection of ever-changing problems whose solutions must seamlessly combine into a single outcome. Examples of design are the activities going into the development of a new computer, the architectural drawings of a new building, or the instructional planning for a new college course.

search in collaborative problem-solving and concludes with a brief outline of this dissertation and definitions of terms.

ABOUT THIS DISSERTATION

The objective of this dissertation is to describe engineering collaboration in terms useful to instructors in Engineering Communication. Many of those instructors would like to give their students opportunities to practice the kinds of oral interactions and group communications typical of engineering design projects in industry. As of yet, however, few communication courses or textbooks have addressed the complexities of collaboration in problem solving. The result is that students may graduate with excellent technical training, and they may be able to write well, but they know little about how to take part in the dynamics of face-to-face problem solving with their peers in team situations. Yet, their ability to collaborate—to do and say those things that help their team think and work at its highest potential—is a critical aspect of their future success.

The general thesis of this study is that sound collective thinking and effective collaborative discourse are mutually sustaining. Certainly individual team members must bring domain knowledge to their project, but no two team members have exactly the same knowledge. To coordinate their thinking and activities, team members must continuously negotiate the construction and maintenance of a common ground of knowledge and assumptions (Clark & Brennan, 1991). As Hutchins says, groups attempting problem solving "accomplish. . . goals by bringing bits of structure into coordination" (Hutchins, 2000), p. 316). Much of collective thinking is audible, heard in the ordinary conversation of team members. Those oral interactions, therefore, serve as windows into the underlying cognitive properties of the group. Is one person doing all the original thinking, while other members nod acquiescence, or are all members proposing, critiquing, elaborating, and otherwise energetically building on each other's contributions? Interactions will tell.

Although instructors in core engineering curricula frequently give their students practice in collaborative problem solving, they usually focus on outcomes, that is, correct solutions. The *process* of collaboration seldom receives attention. Yet, current research suggests that groups have learning processes of their own (Dillenbourg, Baker, Blaye, & O'Malley, 1996; Webb & Palincsar, 1996)}. As Hutchins says, groups are themselves computational units, and they think differently from individuals (Hutchins, 2000). Some instruction in cooperative forms and group learning processes, therefore, would seem to be an essential part of an engineer's training, and courses in Engineering Communication, usually thought of as technical writing courses, seem well positioned in the curriculum to provide that training. As yet, however, surprisingly little is known about the interplay of social and cognitive processes that compose collaborative problem solving in the workplace, much less about methods to re-create that interplay in the classroom. The aim of this study is to help fill that gap.

Summary of Study and Research Questions

This study develops a framework for describing collaborative engineering team problem-solving discourse and applies the framework to examples of actual engineering team discourse. The framework takes into account not only information about the discourse processes but also information about the cognitive and communicative properties of the team members and the effects of the collaborative experience on those members. Specifically, the framework incorporates profile information for each team member as following: (1) preferences for cognitive versus communicative types of engineering tasks and (2) satisfaction with the cognitive versus communicative aspects of project performance. In addition, the framework provides a systematic method for describing the types of cooperative forms that appear in team conversation. Cooperative forms are types of interactions that differ from other conversational structures in that they have purposeful, problem-solving intent shared by the team members. They differ from each other according to the degree that member contributions are symmetrical (the speakers play approximately equally critical roles in the discussion), in alignment (the speakers are cognizant of each other's position), and in agreement (the speakers give some ostensible sign that they are like-minded). Examples of cooperative forms are co-construction and one-sided argumentation. Those cooperative forms can be related to team-level learning processes, that is, learning mechanisms that increase the team's problem-solving capacity in some way.

Together, the task preference profile, the project satisfaction profile, and the interactions themselves make up the descriptive framework for interpreting problem-solving interactions in engineering team discourse.

To summarize, the research questions of the study are as follows:

1. What types of interactive processes appear in the discourse of engineering designers during their joint problem-solving activities?

The research hypothesis is that productive problem-solving discourse is rich in certain types of cooperative forms or patterns.

2. Do engineers differ in which types of engineering tasks are important to them? How can those tasks be categorized?

   The research hypothesis is that student engineers show differences in two major types of preferences: a preference for more individually oriented technical tasks and a preference for more communicative and socially involved tasks. Of course, some engineers show no preference of one over the other.

3. How do member differences in engineering task preferences relate to the types of cooperative forms that appear in team dialogue?

   The research hypothesis is that team members tend to adopt more productive collaborative forms when they have similar or compatible attitudes toward the engineering tasks they share.

4. Do engineers differ in their satisfaction with their project experience, and if so in regard to which aspects of their projects?

The research hypothesis is that engineers differ along two axes: satisfaction with team and individual technical accomplishment and satisfaction with team and individual communicative performance.

5. Is there a relationship between project satisfaction and the types and quality of cooperative forms that appear in team dialogue?

   The research hypothesis is that individual team members find satisfaction in their team and individual performance when they able to function well at *both* the cognitive and communicative levels.

In summary, the focus of this study is on cognitive and communicative behaviors as they appear in interpersonal interactions (Hogan, Nastasi, & Pressley, 2000), and not on their institutional settings. The study is different from other studies of engineering collaboration in that it interprets team-level problem-solving communicative behaviors partly from analyses of team discourse and partly from member differences in cognitive and communicative attitudes going into the project and resulting from the project. Because the factors arise from the engineers' responses to questionnaires, the distribution of the factors in a given team are germane to those particular engineers and may be critical to the team's ability to collaborate effectively. In addition, the study focuses on discourse gathered over a period of weeks, time enough for patterns to emerge that may not appear in studies of shorter-term problem solving.

Study Approach

This study ascribes to two hypothetical statements. The first statement is that problem-solving discourse comprises both social and cognitive processes and that neither of those types of processes can be understood without reference to the other. As some researchers have warned, “Social paradigms built on supposedly clear distinctions between what is social and what is cognitive will have an inherent weakness, because the causality of social and cognitive processes is, at the very least, circular and is perhaps even more complex” (Perret-Clermont, 1991, p. 50). In long-term projects, some tasks (mathematical computations, for instance) are likely to be more cognitive and technical in nature, while others, such as project coordination, are more social and communicative. Nevertheless, both types of tasks entail some blend of cognitive and social processes.

The second statement is that the cognitive processes of the group cannot be regarded independently of those of the individuals composing the group—and vice versa. In other words, the properties of the team members continuously affect collaborative processes and the collaborative processes continuously affect the collaborators. Regarding the first of those propositions, Tudge says, “to make sense of collaborative problem solving (the interpersonal level), one must take into account what each individual brings to bear on the situation. In some cases [referring to previous studies], it simply [is] not clear why some participants [are] more goal oriented than others, some more willing to collaborate and negotiate than others” (Tudge, 2000, p. 7). Regarding the second proposition, that collaboration has effects on the individual members, Dillenbourg et al. calls for a model of the interrelationships between individual learning and social interaction that shows "how dialogue is used as a means for carrying out joint problem solving and how engaging in various interactions may change the beliefs" of group members (Dillenbourg et al., 1996, p. 206). Hutchins combines the sense of both propositions by arguing that any cohesive group of collaborating problem solvers can be viewed as a computational or functional system and that "any attempt to explain the cognitive properties of such a . . . system without reference to the properties of its most active integral parts would be deficient. Similarly, though, any attempt to explain the cognitive properties of the integral parts without reference to the properties of the larger system would also be incomplete" (Hutchins, 2000, p. 287).

Thus any understanding of how a given group solves a problem requires knowledge of the cognitive and social processes that take place, the problem-solving properties of the group members, and the effects of the collaboration on the team members. This generalization provides the rationale for the design of this study.

Theoretical Orientation: Distributed Cognition

This study adopts one of the more recently developed theoretical perspectives of group problem solving in the workplace, distributed cognition [see (Goldberg, 2002; Halverson, 1995; Hutchins, 2000; Hutchins & Klausen, 1996; Rogers & Ellis, 1994; Rogers & Scaife, 1997; Saloman, 1993b)]. In the distributed view, problem-solving groups work in culturally constituted settings that are "rich in artifactual and social interactional resources" (Hutchins, 2000, p. 316). Within those settings, the groups function as computational systems, and cognition is distributed across "agents" (group members and artifacts) (Rogers & Ellis, 1994). Because of the distributed nature of knowledge and skills in the group, it is within agent-to-agent interactions that representations of the problem state are transformed and exchanged across media. Consequently, social and cognitive processes converge and intertwine in the interactions between group members and between group members and artifacts. This integration of what is social and what is cognitive gives theoretical justification for focusing on problem-solving interactions.

In summary, this study adopts the distributed-cognition perspective for two reasons: (1) The distributed view of collaboration regards member-to-member interaction as an effective window into both social and cognitive processes of group activity. An aim of this dissertation is to develop a framework by which to describe such processes in the verbal interactions between application study participants. (2) The distributed view emphasizes the systemic nature of group problem-solving and states that properties of a system and the properties of its elements can be defined only with reference to each other (Hutchins, 2000). An aim of this study is to discover how certain differences (task preferences and project satisfaction) between team members relate to their collaborative effectiveness. Overall, therefore, for better informed and more comprehensive interpretation of engineering team collaborations, this study includes considerations of the conditions, processes, and effects of each team's problem-solving interactions.

IMPORTANCE OF COLLABORATION IN SCIENCE AND ENGINEERING

Projects in modern science and engineering are predominately collaborative. Thagard makes this point indirectly but persuasively by noting the large number of articles in scientific articles that have multiple authors (Thagard, 1997). For instance, out of 558 articles in the scientific journal *Physical Review Letters* (January to April, 1992), 254 (46 percent) had from three to five authors, 167 (30 percent) had two authors, and only 67 (12 percent) had one author. Some articles had 10 authors or more. In contrast, in nontechnical domains, out of 27 articles in the 1992 volume of the *Journal of Philosophy*, only three had multiple authors, and the *Proceedings of the Modern Language Association* (PMLA) that year contained no collaboratively written papers at all.

Thagard suggests several reasons for this prevalence of collaborative work in the sciences and technology. First, multiple team members provide cross-checks on each other's findings, a process ensuring greater overall reliability of results. In addition, the division of labor in most collaborative work reduces redundancy and fosters project-specific expertise, so that the work moves along faster and more efficiently. Because the team encompasses multiple persons, results and interpretations must satisfy multiple viewpoints, a constraint that can strengthen the explanatory power of the results (Thagard, 1997). Finally, many scientific and engineering projects are simply too complex and interdisciplinary for any individual to handle alone. Because of considerations like these, collaboration is the preferred working arrangement among engineers. The days of inventive geniuses working alone in their garages are over.

Besides its practical necessity, collaboration in design activities gives engineers opportunities for improving their work performance (Goel & Pirolli, 1992). Engineers involved in long-term projects are able to work within a "community of practice," that is, a web of relationships organized to facilitate the joint construction of particular items of knowledge" (Lave & Wenger, 1991). Participation in projects with a mix of peers and experts draws new engineers into "a set of relations among persons, activity, and world, over time and in relation with other tangential and overlapping communities of practice" ((Lave & Wenger, 1991, p. 98). Within a community of practice, the participants become immersed not only in authentic working conditions, but also belief systems that valorize behaviors conducive to the practice of engineering. In these ways, the participants experience the complexity and diversity of their field at the same time they receive interpretive support from their partners. Learning and enculturation take place simultaneously, so that newcomers become "involved in the relations with others, make use of the tools and symbols of their work, speak the jargon, and perform the activities that have direct connection with their future tasks" (Lave & Wenger, 1991). Thus, from cultural and historical perspectives, collaboration appears to be a principal means by which the craft of engineering is passed on from one generation to the next.

For successful problem solving, collaboration greatly increases the amount and variety of information accessible to the individual members of a team (Hutchins, 2000). Because the team comprises multiple information seekers, more information is gathered, made accessible, and directed toward the task than would be possible for an engineer working alone. In addition, the individual can observe how relevant information is typically retrieved, represented, interpreted, and acted upon. Individuals begin to "know" more than what is in their head, for they also have access to the knowledge of others (Perkins, 1993). Even the artifacts (tools, computers, instruments) embody knowledge that the individual engineer could not be expected to generate (Hutchins, 2000; Nickerson, 1993; Pea, 1993b).

The effect of this continuous access to a rich information stream is that both individual team members ("persons-solo") and the team as a collective ("people-plus") are constantly refining and augmenting their knowledge (Perkins, 1993). For the person-solo, the individual can learn how the information relates to "higher-order" knowledge, that is, "problem-solving strategies, styles of justification, and inquiry characteristics of the domain" (Perkins, 1993 p. 91). For the person-plus, the effective "access framework" allows team members to see into each other's activities enough to conduct their efforts in parallel or in association (Forman & Cazden, 1985). As Hutchins says, open interactions and inclusion in operational procedures enlarge the participants' "horizon of observation," that is, "the outer boundary of the portion of the task that can be seen or heard by each team member" (Hutchins, 2000, p. 268).

A better practical understanding of collaborative processes has profound implications for research fields such as organizational theory and the technologies of computer "groupware." Activity theory, for instance, has conceptualized organizations as systems of activity, conceptual viewpoint that aids in the understanding of the multilevel interactions and contradictions within institutions and other goal-directed social frameworks (for example, see Engestrom, 1987). Likewise, distributed-cognition perspectives see problem-solving teams as hybrid social-cognitive systems in which knowledge is shared among humans and artifacts. In these systems, cognitive and social processes cannot be separated (for example, Dillenbourg et al., 1996; Hutchins, 2000; Rogers & Ellis, 1994) These new ways of viewing socially constituted cognition have opened up a large multidisciplinary field of research into how computers may support collaborative processes not only *in situ* but over spans of time and space (Dillenbourg, 1999b).

Finally, the principles of collaboration, with its inherent problem-solving processes of negotiation, explanation, argumentation, conflict resolution, and so on, can be seen underlying the relationships among even the largest social entities. Engineers, after all, are in the business of reconciling what humans need or want and what is technically, materially, and economically feasible. To do so, engineers collaborate with each other in teams, and teams interact with other groups (for example, technicians, clients, management, and manufacturers). Likewise, firms employing engineers interact with private and public organizations. Within this widening circle of dialogic engagement, large social systems constantly reproduce and transform (Lave & Wenger, 1991, p 123). Engineers working in collaboration play no small part in bringing about these social, cultural, and material changes.

In summary, both theory and empirical evidence support the position that collaborative practices are indispensable to the execution of socially significant enterprises. Yet, as important as collaboration seems to be, much of the research is still involved in determining just what collaboration is and defining the cognitive and social processes that bind separate individuals into cohesive, problem-solving partnerships.

THE THEORY OF COLLABORATIVE PROBLEM SOLVING

This section first describes the "classical" cognitive perspective on design problem solving, namely, that of Simon and his colleagues. The cognitive perspective places abstract problem-solving processes in the head of the individual solver; however, as stated earlier in this chapter, problem solving also has a social dimension, and a rich store of theory explores the complexities of the interpersonal and group processes of shared undertakings. Consequently, the section traces the steady expansion of the unit of analysis from the learning of the individual (who is influenced by properties of the group) to the learning of groups (which are influenced by the properties of their members). Finally, the section discusses in more detail the hybrid theoretical approach, distributed cognition, which combines elements of both cognitive and social perspectives to describe problem solving in work settings.

The Cognitive Perspective on Design Problem-Solving

The cognitive perspective views knowing, learning, and problem solving as parts of an effort to perceive the organizing principles of a knowledge domain, to which the problem solvers then apply their reason and skill (Greeno, Collins, & Resnick, 1996, p. 18). Many current ideas about problem solving derive from the information-processing theory developed by Herbert Simon and his colleagues (Newell, 1990; Newell & Simon, 1972; Simon, 1973; Simon & Lea, 1974). For these researchers, problem solving consists of a "search in a problem space" (Newell & Simon, 1972). A problem space, in turn, is a representation of the problem in the mind of the problem solver. Within this problem space the designer performs three general types of activity: determination of the problem states (where the designer stands in regard to reaching the goal), determination of what constitutes the goal or how to identify and evaluate a stopping point (in what direction the designer wants to proceed and what constitutes a subgoal), and determination of the operations (for example, rules or equations) that transform one problem state into another, more advanced problem state (what must the designer do to approach the goal or nearest subgoal) (Goel & Pirolli, 1989, 1992). Strategies for searching the problem space include the use of heuristics such as rules of thumb and analogies; the selection of a next step at random; hill climbing (the selection of whichever next step looks most like the goal state); or means-end analysis (decomposing the goal state into subgoals and tackling the subgoals separately) (Dunbar, 1998).

Much of the problem-solving research in the 1970s focused on well-defined (or well-structured) puzzles or games that are solvable in an hour or so (Dunbar, 1998). Reitman, however, described problems, such as engineering design, that are ill-defined or ill-structured (Reitman, 1964); that is, the initial state, goal state, or operators, or all of these are underspecified. In those cases, no two engineers independently of each other are likely to interpret the design problem the same or take the same path across the problem space (Goel & Pirolli, 1989, 1992).

The initial state of ill-defined problem solving is especially critical to the path taken. Without explicit directions, the designer must first give the problem meaningful structure (Simon, 1973). This structuring effort requires the manipulation and synthesis of knowledge from information sources and long-term internal and external memory. Inevitably, the solution to the problem, or rather the form that the solution takes, depends entirely on the particular knowledge that the designer chooses to act upon and incorporate into the design. In team situations, efforts to structure the problem may entail much discussion, and for that reason ill-structured problems are sometimes characterized as "semantically rich," particularly in the initial phases of the project.

Simon took some exception to Rietman's division of problems into those that are well-structured and those that are ill-structured (Simon, 1973). Simon proposed that different problems fall at different points on a continuum from ill-structured to well-structured, depending on the skill and resources of the solver. As the nature of the problem becomes clarified, the problem moves farther toward the well-structured end of the continuum. Consequently, in Simon's view the same heuristics or rules can be applied in either case, and hence no problem is intrinsically ill- or well-structured (Simon, 1973). From this line of thinking, Simon defined *design* broadly as the course of action one takes to change an existing situation into a preferred one (Simon, 1981, p. 130), a definition that hardly distinguishes design from any other type of problem.

Goel and Pirolli define design in much more restrictive terms (Goel & Pirolli, 1989, 1992). These authors employed think-aloud protocols in a study of professionals solving complex real-world problems representative of their disciplines—mechanical engineering, instructional design, and architecture. The authors identified features of design problem solving that they claim are the same across the design disciplines (see Appendix A for the complete list). These features include activities such as problem structuring and dividing the problem solving into phases. The designers continuously adjust their definition of the problem in keeping with available resources. Frequently they decompose the problem solution into mutually contingent modules and work on these separately with the idez of combining them at some later stage. They interactively develop and refine interim solutions as the design unfolds, and sometimes they must commit to less-than-ideal decisions. Decisions regarding when they have gone far enough in their design of a module or final product may be based on personal standards. Throughout the design effort, designers use symbol systems (sketches, notes, schematics, flow charts, utterances, equations, and so on) extensively. These means of representing the problem help the designers plan and control their activities, visualize processes and relationships, and reduce the demands on memory (Goel & Pirolli, 1992). In fact, the final design product is often couched in a symbol system (a set of specifications or engineering drawings) for use in fabrication or implementation. Goel and Pirolli argue that these activities are generic to all complex design projects.

The cognitive approach, then, involves a high-level analysis of the structural nature of the design problem and the set of cognitions generic to design. The approach makes scant reference to whether the designer is an individual or a team or whether the designer is working in a garage or engineering laboratory. In truth, however, design is impossible outside a social and physical setting. First, engineering design projects are generally too large, complex, multidisciplinary, and time constrained for any single designer to carry out alone (Gunther, Frankenberger, & Auer, 1996). Second, the resources and affordances within a given setting exert a profound influence on critical design decisions (Bucciarelli, 1988, 1994; Perry, 1997).

The cognitive perspective, however, does give a suggestion of social and environmental interactions. For example, the problem-definition and planning phases of design, characterized as being semantically rich, can be expected to involve numerous explanations, negotiations, and other face-to-face interactions if team members are to agree on how their time and effort together will be spent productively. For another example, the decomposition of a design problem into subtasks surely requires negotiation and agreement among team members as to a logical division of labor, and afterwards the different members must coordinate their work on assigned modules with the work of others on their modules (Perry, 1997). If the design components are to come together seamlessly, this cooperation should entail a rich exchange of communications and mutual regulation. No less important than the social factors are the environmental factors. Every tool, device, and other affordance in a design environment imposes its own constraints on how the problem is represented, understood, and solved (Gibson, 1979; Hutchins, 2000), and the layout of workspace (ranging from the workbench to networks of remote sites) governs the cooperative forms and communication modalities available to the design team (Rogers, 1992).

In short, the cognitive perspective is a useful theoretical starting point to understanding the abstract cognitive structure of design problems. It takes as its unit of analysis the individual problem solver making sense of the problem seemingly in isolation. Thus, the design problem space is located in the solver's head, and problem solving is represented as a search for a path across that space. This decontextualized approach, however, ignores the rich network of interactions between designers (Rogers & Ellis, 1994), and for that reason many researchers in sociology have criticized the cognitive perspective as too restrictive, saying that such a narrow focus on the problem structure precludes consideration of the social dimensions of problem solving, or "practical reasoning" (Heath & Luff, 1991).

Social Perspectives on Collaboration and Learning Processes

The following sections briefly summarize major social perspectives on learning and problem solving and highlight the important learning processes associated with each. Note that the perspectives are discussed in a general order that reveals a steadily expanding "problem space," or unit of analysis—from those focusing on the individual responding to social influences to those focusing on entire groups and the interactions of their members. Another trend is the gradual shift from the study of children in learning situations to adults in problem-solving situations within larger communities. Even so, the various social perspectives are highly complementary: one builds upon the insights from others. Also note that the social perspectives do not focus on design as a special case of problem-solving, but rather on problem-solving as a social process that pervades any collaborative and goal-directed effort.

Piaget and Cognitive Conflict

Piaget's sociocognitive theory (see, for example, Piaget, 1932, 1970, 1977/1928; Tudge & Winterhoff, 1993) proposes that children's learning is influenced or instigated by events in the world around them. Children are active learners who constantly compare new information with what they think they already know. Where there are discrepancies, the child feels a temporary sense of disequilibrium, which in turn initiates a process of assimilation or accommodation. Assimilation is the process by which the child interprets events in light of his or her current knowledge structures and incorporates the new information in such a way that it fits. Accommodation is the process of interpreting events and consequently modifying their knowledge structure to be consistent with the perceived realities. The social condition that invokes either process is sociocognitive conflict, which most naturally arises at play or work with peers. With peers, as opposed to adults, the child feels free to explore and argue alternative perspectives.

Though there is a social component to Piaget's theory, it still puts the focus on cognitive change in the learner's head. Sociocognitive conflict, however, may have a role in group learning situations as well (Dillenbourg & Schneider, 1995), because the resolution of a conflict between the views of group members implies some degree of argumentation (Baker, 1998) and explanation (Chi, Bassok, Lewis, Reimann, & Glaser, 1989), both social mechanisms for "informating" (Zuboff, 1988) the group environment. The process of resolving a conflict together raises the level of thinking of both partners (Dillenbourg & Schneider, 1995; Doise & Mugny, 1984). Moreover, when members must consider two or more alternatives or plausible hypotheses, they are better able to avoid the pitfall of confirmation bias, that is, the tendency of a person to see most clearly only that which the person already believes (Hutchins, 2000).

Vygotsky: Internalization and Scaffolding

Vygotsky argues that new knowledge first appears spontaneously between the learner and an adult or more experienced peer; that is, both persons generate knowledge on their plane of shared and interwoven understandings of the problem[2] and their awareness of each other's perspectives (Forman & Cazden, 1985; Rogoff, 1998; Tudge & Winterhoff, 1993; Vygotsky, 1978, 1981; Wertsch, 1985). Rommetviet refers to this intermingling of thinking as *intersubjectivity* (Rommetveit, 1985). The learner internalizes the new knowledge (that is, processes it on the intrapsychological plane), and when it re-emerges on the social plane, the knowledge may or may not have undergone a degree of transformation. For internalization to occur, the interaction must take place in the child's zone of proximal development, where the learner and more experienced partner, using mediational tools or language, co-construct solutions to problems just beyond the capacity of the child to solve alone (Tudge & Rogoff, 1989; Vygotsky, 1978; Wertsch, 1984, 1985).

With the emphasis in the theory on productive interactions between the learner and a more knowledgeable other person, Vygotskian research has focused on what those interactions might entail. For example, an important learner-expert interaction in the literature is called *scaffolding* (Wood, Bruner, & Ross, 1976). Scaffolding is a technique by which the expert engages the learner's attention and guides the learner, at the learner's pace and with regard to the learner's perspective and psychological readiness, through the zone of proximal development.

[2] Note that the word "problem" is used generically here to refer to any specific situation in which the child recognizes that he or she lacks the necessary knowledge or skill to function according to a perceived standard.

Scaffolding, however, concentrates on the activity of the more knowledgeable person in the partnership, and little is said about the mutual effects the two partners have on their understandings of a problem (Rogoff, 1998). Even the expert in the partnership must organize and tailor his or her knowledge to conform to the contingencies of the situation and the understanding of the learner, and those processes can be expected to transform in subtle ways the expert's own understanding of the problem. Moreover, any restriction of scaffolding to interchanges between adult/experts and child/novices may be too exclusive. For example, in the case of peers working on complex design problems, no two persons are likely to have the same strengths and weaknesses in all topic areas, so that scaffolding roles may shift back and forth as first one then the other peer evinces more knowledge than the other (Miyaki, 1986).

In Vygotsky's hands, internalization is not intended as an explanation of group learning, and the zone of proximal development is defined in terms of the learner's need, not that of the group. On the other hand, there seems no reason why two peers could not engage in co-construction within their *collective* zone of proximal development. In fact, Engestrom has given the definition of the zone of proximal development a distinctly social twist: "the distance between the everyday actions of individuals and the historically new form of the societal activity that can be collectively generated" (Engestrom, 1987, p. 174). Moreover, although two peers internalize the same lesson learned, there is little likelihood that the knowledge that re-emerges on the interpsychological plane will be the same. That difference, however, can be quite salutary, because both peers would then be engaging with each other from positions of greater understanding. Despite the limited application of Vygotsky's ideas to collective processes, his conceptualization of learning as being a phenomenon that takes place between people, and not within them, remains a fundamental principle of social theories of learning and problem solving.

Rogoff and Appropriation

For Rogoff and other sociocultural theorists, learning is equated to the learners' acquisition of behaviors that qualify them for participation in socially constituted situations (Lave & Wenger, 1991; Rogoff, 1990, 1998; Wertsch, 1991a, 1991b; Wertsch, del Rio, & Alvarez, 1995). Thus, learning takes place within sociocultural activities, and as learners develop, their participation deepens and undergoes transformation to prepare the learners for meaningful social roles and relationships. Individual, interpersonal, and group processes are mutually dependent and cannot be understood separately, and learning itself is contingent on the surrounding social and cultural circumstances. Through communication and coordination, the participants in a social situation continually adjust to each other according to the new perspectives of the shared endeavor (Rogoff, 1998).

The opportunistic aspect of learning-in-contexts is embedded in Rogoff's description of appropriation, in which the mind's acquisition of knowledge is comparable to the body's incorporation of water and air (Rogoff, 1990, p. 195). When learners are already participating in an activity, they are in a position to learn by observing the language, operations, and use of tools around them, and they appropriate these elements into their own systems of activity as they recognize their utility and understand their use. Moreover, as Newman et al. (1989) state, appropriation is always a two-way process. The knowledge that is adopted is itself changed as it enters into the activity system of a new member of the culture (Newman, Griffin, & Cole, 1989). In addition, although Rogoff discussed appropriation in adult-child interactions, the mechanism applies to adult-adult peer interactions (Dillenbourg & Schneider, 1995). In peer interactions, for instance, one partner can witness how his or her actions or expressed ideas are taken up by other partners and incorporated into their own plans. The first partner learns from the way the other, perhaps more experienced partners respond to the original action. A general visibility into the way ideas are disseminated and taken up by members may be a powerful group problem-solving advantage.

Lave and Wenger: Communities of Practice and Legitimate Peripheral Participation

Similarly to Rogoff, Lave and Wenger define learning as situated participation in a community of practice, where the newcomer learns the talk, roles, and perspectives of the oldtimers (Lave & Wenger, 1991). In Wenger's terms, a community of practice "is a joint enterprise, as understood and constantly renegotiated by its members," that produces a "shared repertoire of communal resources (routines, sensibilities, artifacts, vocabulary, styles, etc." (Wenger, 1998). The newcomer engages with a community of practice through a process called legitimate peripheral participation. The participation is legitimate because the newcomer is given the prerogatives of a member and right of access to all the collective sources of understanding. The participation is peripheral because the newcomer may participate wherever in the field of practice he or she is able to contribute.

As learning progresses, the newcomer assumes more central roles and identities in community life and eventually achieves parity with the oldtimers.

All learning in a community of practice is situated, because learning arises from practical problems and contradictions that are inevitable in day-to-day operations. As the newcomers pass into fuller membership, they become more involved in the solution of those problems. Their motivation is pride of accomplishment and the self-esteem that comes with membership in the community. On the community's part, the continuous flow of newcomers moving toward full participation and replacing the cadre of oldtimers represents a regenerative process that both ensures the future of the community and allows the community's adaptation to changing circumstances and resources.

Suchman and Situated Action

The situated-action theory of Suchman (Suchman, 1987) regards the organization of activity as contingent on and emerging from the moment-by-moment interactions between humans and between humans and their environment. Interaction, in turn, is the process of individuals trying to make sense of a situation and to reach common understandings. Thus, action emerges in a commonsense way from local circumstances. Structures, plans, intentions, or procedures are "retrospective reconstructions" of spontaneous actions whose meaning can only be understood within the immediacy of the situation (Suchman, 1987).

This emphasis on responsiveness to changes in the environment and the improvisational nature of action calls for observational methods that capture thoughts and exchanges made in the pitch of the moment. The best way to see this joint sense-making is to observe the everyday conversation of the actors. As Suchman says, language "stands as a generally indexical relationship to the circumstances that it presupposes, produces, and describes" (Suchman, 1987, p. 57). For that reason, situated-action research consists of minute examinations of verbal and nonverbal communication and employs the conceptual and analytical tools of ethnomethodology (Garfinkel, 1967), speech-act theory (Austin, 1975), and conversation analysis (Sacks, Schegloff, & Jefferson, 1978; Schegloff, 1991; Schegloff, Jefferson, & Sacks, 1977).

While meticulous conversational analyses provide precise dissection of problem-solving discourse, they are often narrowly focused on short sequences of utterances. Larger patterns of communicative and cognitive patterns may go unobserved (Baker, 2002). This problem is especially pronounced in the study of long-term problem solving, where various types of interactions may link up into patterns of coordination and team regulation. At the other extreme, Lave and Wenger's community of practice may be too broad an analytical unit for observing interactional behavior.

Activity Theory and Mediated Action

Activity theory views human activity in work settings as encompassing individuals in interaction with goals and communities and stresses the mediating effects of tools, social rules, and division of labor in the operations of an activity system (Cole, Engestrom, & Vasquez, 1997; Engestrom, 1987, 1993; Engestrom, Miettinen, & Punamaki, 1999; Kuutti, 1996; Leont'ev, 1981b; Nardi, 1996; Wertsch, 1981, 1991b; Wertsch et al., 1995). According to activity theory, actions take place in specific contexts, which include the physical setting and resources, purposes of the enterprise, roles, and assumptions. Within those contexts are tools that mediate action, and these tools may be material or symbolic. Examples are instruments, machines, signs, procedures, laws, language, specifications, and so on. Each mediational tool has embedded in it all the thought and design that has gone into its historical development, and all of that embedded cognition is made available to the current user without his or her having to rethink it. Its history and even its use, once it is mastered, become transparent to the user (Kuutti, 1996; Leont'ev, 1981b).

Action is what a subject does to transform an object (or objective) into an outcome. The subject, the object, and the mediating tool or sign make up an elementary activity structure. Because activity in work enterprises has a collective nature, the concept of community (those who share the same object) is added to that activity structure (Engestrom, 1987). The interactions between the subject and community, on one hand, and object and community, on the other, are themselves both mediated (all interactions are mediated). Thus, subject-community interactions are mediated by rules and conventions of behavior, and the object-community interactions are mediated by divisions of labor. In this dynamic system, each part (subject, object, community, etc.) interacts with the other parts. Even when a subject is transforming an object, properties of the object are also producing change in the subject.

Activities are hierarchical in structure (Kuutti, 1996; Leont'ev, 1981a). An activity (for instance, developing a software package) is related to motive (a plan or model) and consists of actions, or chains of actions (for example, writing code for a module, consulting with a programmer), that advance the subject to a goal. Actions are related to goals and consist of operations, or chains of operations (for example, keyboarding commands). When an action becomes more or less automatic, it may become an operation, and conversely, an operation, when it becomes problematical, may become an action.

Activity theory provides a powerful tool for viewing interactions within the framework of a dynamic activity system; however, the theory seems better suited for analyzing the multiple-layered interactions in larger social systems, such as institutions and organizations. For the purposes of this study, the theory seems somewhat cumbersome for an analysis confined to the problem-solving interactions within a small group of engineers.

A Hybrid Approach: Distributed Cognition

Distributed cognition is an analytical framework for the study of cooperative problem solving in workplace settings (Goldberg, 2002; Halverson, 1995; Hutchins, 2000; Hutchins & Klausen, 1996; Rogers & Ellis, 1994; Rogers & Scaife, 1997). For Hutchins and his colleagues, individual cognitions are always a part of the computations of larger social systems. Hutchins' well-known example of a computational, or functional, social system is the navigation team of a large ship as the team repeatedly takes positional fixes (Hutchins, 2000). No single individual on the bridge of the ship can guide the vessel to anchor alone; instead, navigation is the result of numerous cognitions distributed over a number of individuals and instruments all working in coordination. Whatever the individual does is a contribution to what the system does, and ultimately it is the collective thinking of the navigation team that brings about a meaningful outcome. In distributed cognition, therefore, social and cognitive processes become indistinguishable.

In the distributed view, social systems have cognitive properties of their own. The computation performed by a social system consists of the "generation, transformation, and propagation of representational states across a variety of media" (Hutchins, 2000, p. 49). A representational state is a configuration of the elements of a medium that can be interpreted as a representation of something, a problem, for instance. The media are means of storing information, and they include both internal memory (human) and external memory (computers, graphs, etc.). When information is propagated from one medium to another, their representational states are brought into coordination. For example, a gyrocompass provides a set of numerical readings denoting the ship's spatial relationship to known landmarks. When those instrument readings are transformed and propagated to the grid of a map, they become lines, with their intersection designating the ship's position. The readings of the gyrocompass and the markings on the chart are synonymous, yet the representation on the chart is more overtly expressive of the problem solution (p. 117). Solving a problem, therefore, means representing and re-representing information "to make the solution transparent" (Simon, 1981, p. 153). Simon compares this representation-transformation-re-representational process to the proving of mathematical theorems, when the application of transformative rules carefully preserves the truth of the axioms (Simon, 1981). Hutchins proposes that the same process applies to the computations within problem-solving groups, only the process unfolds horizontally across media (Hutchins, 2000, p. 118).

Group cognition makes itself evident through the interaction between team members and between them and their instruments. Interactions are observable events, and as information is propagated through the system via interactions, the cognitive organization of the system becomes apparent. Even details in an individual's head, while not directly observable, can be assumed to arise from local circumstances since they are "residua of a process enacted by a community of practice rather than idiosyncratic inventions of the individual" (p. 130). The cognitive role of the individual is to provide the "internal structures that are required to get the external structures into coordination with one another" (p. 131).

Artifacts in the environment have two purposes: they serve as representational media in which the computation is achieved by the propagation of representational states, and they provide constraints on the organization of action. They do not amplify cognition; they can only transform the task the person has to do by representing it in a domain where the answer or path to the solution becomes more apparent (p. 157). A difficult task is transformed into simpler ones, like pattern matching, manipulating simple physical systems, and performing elementary mental calculations. A change in the nature of the task requires changes in the coordination of representational media, which in turn leads to changes in the organization of the computational social system.

Language is an important example of a structured representational medium (p. 231), and, as with any other artifact, its nature constrains the computational character of the system. Individuals understand utterances by bringing them into coordination with other external or internal representational media. "The impact of the message on the receiver depends on what the receiver already knows" (p. 141). As Hutchins says, "when cognitive activities are distributed across social space the language or languages used by task performers to communicate are almost certain to serve as structuring resources, and the structure of language will affect the cognitive properties of the group" (p. 232).

Communications are also important because they provide a task-focused learning context for its practitioners. Task knowledge is never distributed evenly, and there may be questions of what knowledge is relevant, as in the case of poorly defined problems. At any given time, some knowledge is redundant, and some knowledge is discrepant or conflicting (Rogers & Ellis, 1994). Consequently, team members may frequently engage in various types of verbal and nonverbal interactions to identify areas of agreement, to clarify ideas, and to negotiate conflicts, among many other purposes. By these interactions, the members co-construct a "common ground" of shared knowledge, beliefs, and suppositions (see Clark & Brennan, 1991; Clark & Schaefer, 1987). Through interactional processes, members of the group continually make adjustments to each other to optimize the distribution of information and to process the information for inclusion in the common ground. In addition, all members have access to new information as it enters anywhere in the system (Hutchins, 2000), and that new information receives the same kind of screening for general acceptance. At times, patterns of communication in the system may have the effect of scaffolding learning, or they may entail the generation of new knowledge.

At the system level, conceptual change is a product of local adaptations in a dynamic system of members and artifacts actively engaged in the coordination of representations (p. xvii; 347). Because the system comprises interlocking, interacting membership, changes (in roles, rules, etc.) must meet the constraints of all members, or all members must be persuaded that a change is beneficial. Members usually recognize the need for a change during local situations, when they must adapt to changes or imperatives in the environment. When the change propagates through the system, the system in effect "discovers" the change. According to Hutchins, "to the extent that the acquisition of useful adaptation to a changing environment counts as learning, we must say that this is a case of organizational learning" (Hutchins, 2000, p. 349). The group, therefore, is a learning entity not by external design but by internally driven evolutionary processes of search and small adaptations at local situational levels (p. 349).

This expansion of analysis to include the cognitive properties of a system of problem solvers and their tools in a problem-solving task seems appropriate for the study of a team of engineering designers. Just as a navigation crew guides a ship through coastal waters, an engineering team steers their path through a problem space (Perry, 1997). Along the way, they generate representations of current knowledge states and through language and other media repeatedly transform those representations through intermediate stages toward the final goal. The properties of the individual are pertinent, but only in conjunction with the properties of the other individuals as well as with the environmental resources or constraints, for it is the team's collective effort that generates problem solutions. Cognition takes place through interactions that coordinate problem representations.

In this way, distributed-cognition places the study of engineering communications in a social and cognitive framework. Though not a perfect theoretical fit for the study of ill-defined problems such as engineering design (which is not as orderly, well-coordinated, and stable as, say, navigational procedures), distributed cognition gives researchers a plausible framework for the study of interactions between members of engineering teams.

Implications of Theory

The foregoing review of the theoretical perspectives on collaborative problem solving suggests the complementary relationship of cognitive and social processes and between individual and group processes. The challenge is to discover how these conceptual pairs can be reconciled in a single theoretical view of peer collaboration and cognitive development (Dillenbourg et al., 1996; Tudge, 2000). Of the perspectives discussed, the hybrid approach, distributed cognition, seems to combine elements of the cognitive and the social perspectives to yield a consistent view of group cognition. First, it recognizes cognition as a type of context-dependent activity, so that the theory seems especially applicable to an analysis of group problem solving in work settings. Second, it treats collaborating problem solvers as working in computational social systems in which the members have mutual effects on their cognition. Third, it recognizes the importance of interaction between members (and between them and their environment) as the process through which problem representations are propagated; therefore, the conditions, processes, and effects of these interactions are central to the theory. For these reasons, distributed cognition provides the current study with its rationale for focusing on interactions for insights into engineering design problem solving.

The following paragraphs address some of the implications and issues related to the distributed-cognition perspective and its use as a theoretical approach to a study in engineering collaboration.

The Systems View

Recently, new technologies like computer-assisted cooperative work and human-computer interaction have created an interest in a "distributed" view of collaborative problem solving (Dillenbourg, 1999a; Goldberg, 2002; Hutchins, 2000; Lave, 1988; Lave & Wenger, 1991; Pea, 1993b; Resnick, 1991; Rogers & Ellis, 1994; Roschelle & Teasley, 1991). A computer, after all, cares little whether it is supporting one problem-solver or a hundred at a given time; it cares only about the problem-solving capacity distributed among the members (agents) of the network (Dillenbourg, 1999a; Dillenbourg et al., 1996). For that reason, the distributed-cognition perspectives have taken on importance in the research because it proposes that thinking in collaborative practice is inside *and outside* of the head (where the computer can deal with it), so that group members and their local situational elements fuse into single cognitive or functional systems. Thinking is a socially shared phenomenon, which is why Perkins refers to problem-solving teams as "people-plus" systems (Perkins, 1993).

Viewing a design engineering team as a socially constituted system helps in the understanding of ill-defined-problem solving as an open-ended process (Perkins, 1993;

Saloman, 1993b). On one hand, the functionality of a system is robust compared to that of an individual. The system remains even though individual members come and go—but not without a change in its cognitive properties. On the other hand, in a system a solution path emerges from the multiple perspectives, mutual constraints, and complex interactions of its membership. Thus, in contrast to the cognitive perspective, the systemic view provides a distinctly social explanation for the multiplicity of solution paths for ill-defined problems. Systems allow considerable interplay between their members, which is to say that members of an engineering team have multiple ways of relating with each other, their tools and resources, and the nature of the problem (Engestrom, Engestrom, & Karkkainen, 1995).

This shift in theoretical perspective from the individual to the system is not without theoretical and empirical difficulties (Dillenbourg, 1999a; Dillenbourg et al., 1996):

First, does a focus on group learning mean the depersonalization of the learner and the abandonment of efforts to understand individual learning in social settings? (Perkins, 1993; Saloman, 1993a). The system approach tends to abstract away from the human problem solvers themselves and their varied and unpredictable cognitive and social properties. By conflating the problem solvers and their tools, distributed-cognition theorists are emphasizing that one cannot expect to understand the goals or the processes of a system by examining "the properties of individual agents alone, no matter how detailed the knowledge of the properties of those individuals might be" (Hutchins, 2000, p. 265). This stance, however, has led Coles et al. to ask, "Are psychologists to give up on the analysis of individuals altogether and abandon psychology's traditional mission?" (Cole et al., 1997, p. 5).

Second, the expansion of analysis to include larger social aggregates also multiplies the number of parameters to deal with and greatly complicates empirical efforts to flesh out the new perspectives (Baker, 2002; Dillenbourg et al., 1996; Webb & Palincsar, 1996). What are the conditions for successful collaboration and group learning processes? What do individuals do to make their groups successful?

Third, a focus on groups solving ill-defined problems in the work place complicates the identification of appropriate measures of group success. In the workplace, by what standards can one say a group is successful when the degree of problem difficulty or the availability of resources is unknown?

The Focus on Interactions

Distributed cognition states that the dynamic interplay of social and cognitive processes of group problem solving becomes apparent at the interactional level (Dillenbourg et al., 1996; Hutchins, 2000). It is through interactions and interpersonal communications that team members coordinate their separate representations, make their skills and knowledge known to one another, negotiate meaning, and reach agreement. In addition, the language used in interactions reveals the team's metacognitive processes. As problems become longer and more complex, more interactions are devoted to the coordination of team activities (Barron, 2000). Most importantly, with interactional processes as their focus of inquiry, researchers can identify the various cooperative forms that arise in discourse and relate them to learning mechanisms. Finally, they can determine to what degree different types of interactions depend on variables in team composition (including the intellectual and communicative properties of the members) and the nature of the task (Dillenbourg et al., 1996).

Like sociocultural theory, the distributed cognition framework employs the notion that interactions have reciprocal effects on the knowledge states of the interlocutors. The conversational act of explanation provides an example of this two-way effect (Chi et al., 1989). While a less knowledgeable partner may benefit directly from a partner's explanation, the explainer also benefits from the process of organizing his or her declarative knowledge and making procedural steps explicit (explicitation). Other examples of mutually beneficial interactions are co-construction, co-argumentation, and co-elaboration (Baker, 2002; Dillenbourg, 1999a). Each of these forms of cooperation invokes conversational processes that continuously upgrade the knowledge state of the interlocutors *taken together* as well as individually.

Applicability to Design Problems

Perry (1996) points out several differences between well-defined problems like navigation and ill-defined problems like design. In navigation, team members are restricted to internal resources of information and participation, but design is an open process in which members must identify, collect, and interpret promising information from whatever external resources are available. Navigational problems have clearly specified goals, but "designers learn about the problem during problem solving" (Perry, 1997, p.

70). No two design problems are the same, so that a part of a current problem is to define the problem itself as well as the techniques to solve it. Procedures evolve during the course of solving the problem. Navigational teams have an established organizational structure that specifies communication pathways (p. 70). Design has no predetermined organizational structure, and communication pathways change depending on how the problem develops. Navigation solutions are "snapshots" in time, whereas a design solution continues to develop sometimes for years, and the solution is completed only when the participating parties agree that it is. Design has no precedents to determine a stopping point.

Navigation and design, however, are both collaborative processes involving the propagation of representational states across media. In both cases the structure of the problem and the social and cognitive processes of the group to solve the problem are revealed in the interactions between members and artifacts. In the case of design, there may be more repetitive interactions and re-representations of problem states, but the same cooperative forms and group processes can be expected in problem-solving discourse. The research focus on interactions is applicable in both cases.

The Question of Motivation

Each of the theoretical perspectives considers the incentives for an individual to participate in problem-solving activity, and those incentives generally relate to the unit of analysis of the perspective. For example, the cognitive perspective attributes a learner's willingness to engage in problem solving to the learner's natural interest or curiosity as to the structure and underlying principles of a problem (Greeno et al., 1996). The problem solver is intrinsically motivated to devise the strategies to explore domains that already have the learners' interest. Likewise, Piaget's sociocognitivism takes the view that children are naturally active learners who attempt to reconcile their experience with their current knowledge structure (Piaget, 1932, 1970). Running through the sociocultural perspectives is the principle that learners attempt to take on increasingly significant roles in socially valued activities to achieve an identity as a contributing member of the community (Rogoff, 1990, 1998). The shared-learning and distributed-cognition perspectives place even more emphasis on the learner's need for identity as a member of a community of practice (Lave & Wenger, 1991).

The question becomes one of understanding how the individual learning incentives and incentives for working in a group may converge (Dillenbourg et al., 1996; Slavin, 1996; Webb & Palincsar, 1996). From the shared-learning framework, for example, it can be supposed that one's identity as a member of the group is socially reinforced whenever that member contributes meaningfully to the group's activities. Individuals performing well receive some form of positive response (or at least no negative response) from their peers; individuals performing poorly do not. This social reward, in turn, suggests that individual team members will wish to funnel their efforts toward group-valued goals; that is, they adopt the group's goals as their own. Because they cannot meet those large goals on their own, the individual members must not only make their own contribution to a solution but also help other members make theirs when necessary. At the micro level, therefore, this mutual support may take the form of any of a number of productive interactions, such as scaffolding, explanation, critiquing, argument, and conflict resolution, all of which increase the problem-solving capacity of the group.

Summary of Theory

The evolution of the theory of collaborative problem solving suggests a continuous tension between what is cognitive and individual and what is communicative and social. Recent theoretical work in distributed cognition, however, has explored the idea that cognition *is* inescapably social, and it is distributed across the members and artifacts of a problem-solving group, or computational system. This view seems most persuasive when applied to well-defined and well-ordered collaborative or cooperative problem solving, such as fixing the position of a ship or piloting a airplane. In such cases, the problem solvers have predefined and habitual roles to play in the larger system. Their individual cognitive and social properties are suborned to the needs of their well-practiced tasks. For poorly defined, long-term, and complex problems, such as defining and planning a unique solution to a design problem, the cognitive and social properties of the group member have more scope to emerge and intertwine with those of other members. On the part of the team member, learning to recognize and capitalize on those properties becomes a part of the collaborative process of working together to build a common ground of knowledge. On the part of the researcher, to reach an understanding of collaborative problem solving at the system level requires a close examination and principled characterization of the properties of the participants, the cooperative forms of the interactions, and the outcomes of those interactions.

OUTLINE OF THIS STUDY

This chapter has provided the thesis and research questions that have guided work on this study. In addition, the chapter has described the importance of collaboration in the work of scientists and engineers and has reviewed the collaboration theory that is the foundation of the study. The next chapter, Chapter 2, Research Issues in Collaborative Problem Solving, reviews recent research on group processes and social learning mechanisms. In addition, the chapter will describe cooperative forms as described by Baker (2002). Productive cooperative forms include co-construction, co-elaboration, co-argumentation, and one-sided argumentation.

Chapter 3, Methodology, presents a framework for describing the collaborative discourse of working engineers. First the chapter describes the instruments and analyses by which a sampling of engineering students indicate their preferences for any of a variety of common engineering tasks and their satisfaction with the cognitive and communicative quality of their collaborative project experience. This information is used to help interpret the interactions of participants in examples discourse from teams (three two-person design teams). In addition, the chapter summarizes the procedures for capturing discourse data from the teams, analyzing the transcribed protocols for cooperative forms and other information, and relating the discourse characteristics to differences between the team partners.

Chapter 4, Questionnaire Results and Generation of Engineer Profiles, describes the results from the statistical analyses and identifies the variables that will help define individual differences between the engineers of any given team.

Chapter 5, Three Applications of the Interactional Framework, describes the results of the application of the descriptive framework to the discourse of three engineering teams, with emphasis on how differences in given variables seem to affect the pattern and types of cooperative forms the teams make use of in their collaborative efforts.

Finally, Chapter 6, Discussion and Conclusion, will discuss the implications of the study results for research into project- or problem-based learning activities in engineering contexts.

DEFINITIONS

The literature of collaboration and group processes contains two pairs of terms that are sometimes strictly differentiated and at other times are used interchangeably. They are *collaboration*/*cooperation* and *learning*/*problem solving*. The following paragraphs discuss their use in this study.

Collaboration and *Cooperation*

Much of the research in group problem solving has focused on the learning benefits of a particular form of cooperation between partners, namely, *collaboration* (see Rogoff, 1998, for a review). Collaboration involves interactions in which both partners initiate new ideas, with each member's ideas arising from and reinforcing the other's

(Roschelle & Teasley, 1991). It involves “a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem” (Roschelle & Teasley, 1991, p. 70). Thus, collaboration is akin to co-construction of meaning (Baker, 2002). The cognitive processes of the participants are intertwined. Some researchers (for example, Goldberg, 2002) argue that engineering projects are inherently collaborative, because they rely on shared vocabulary and shared awareness.

For example, engineers observing and discussing experimental results at the workbench might jointly construct the meaning of what they see. Collaboration optimizes the use of intellectual attributes of the engineers because they are thinking together beyond a level they can think apart. In contrast, *cooperation*, according to Roschelle and Teasley (1991), is coordinated activity in which individual participants take on different portions of the problem; that is, the work is divided hierarchically and performed in parallel. Thus, cooperation implies a “division of labor among participants,” and individuals are responsible for portions of the problem solving.

In this study, *collaboration* and *cooperation* will be used interchangeably to refer to joint problem solving in general. Wherever the difference matters, however, the words will be used according to Roschelle and Teasley’s definitions above. Note that sometimes it is hard to tell whether a team is collaborating or cooperating. For example, in their discussions collaborating team members often fall into cooperative modes of interaction, with the more knowledgeable partner generating new information while the other partner critiques, questions, and supports (see Miyaki, 1986).

At the level of a cognitive system, collaboration (co-construction) may be an effective form of cooperation for a group, but it is not the only form (Baker, 2002; Dillenbourg, 1999a; Dillenbourg et al., 1996). Examples of other forms of cooperation are co-elaboration and co-argumentation. (Baker, 2002). In practice, large projects such as those in engineering design are so complex that task features, team composition, schedule pressure, and division of responsibilities may compel team members to cooperate from time to time in whatever ways are expeditious.

Learning* and *Problem Solving

Unless stated otherwise, this study makes no distinction between *learning* and *problem solving*. In so doing, it follows the precedent established in developmental and sociocultural psychology. For example, Piaget's and Vygotsky's experiments usually involved subjects who were attempting to solve well-defined problems of various standard kinds (Tudge & Rogoff, 1989). In those studies, experimenters looked for evidence of conceptual change, or development of higher mental functioning, and that evidence was often tantamount to the successful solution of the problem. Note, however, that work in other fields, for example, some branches of artificial intelligence, carefully distinguishes between system or agent learning and problem solving (Dillenbourg et al., 1996).

CHAPTER 2
RESEARCH ISSUES IN COLLABORATIVE PROBLEM SOLVING

Research in collaborative problem solving and group processes has been active in four broad areas: the effects of collaboration, the conditions for productive collaboration, types of group learning processes, and the nature of interactions and cooperative forms (Dillenbourg, 1999a; Webb & Palincsar, 1996). This chapter briefly reviews the research in each area and relates the research to the goals of this study.

EFFECTS OF COLLABORATIVE PROBLEM SOLVING

Many early empirical studies on collaborative or cooperative learning have attempted to determine whether or not individuals learned more efficiently when working with others than they did when working alone (see E. Cohen, 1994; Slavin, 1983; Webb, 1991; Webb, Troper, & Fall, 1995, for reviews). The results of that research have been contradictory (Saloman & Globerson, 1989; Schwartz, 1999; Slavin, 1983; Webb, 1991). For example, some reviews of the research literature (Webb, 1991, and Slavin, 1996) concluded that cooperative learning has a generally positive effect on learning outcomes, provided that there is a good deal of elaboration of ideas in the dialogue. Other researchers (for instance, Schwartz, 1999) argue that years of research has produced few "demonstrations that working in a small collaborative group yields cognitive outcomes that cannot be matched or exceeded by the most competent member of the group" (p. 197). Salomon and Globarson (1989), moreover, describe scenarios in which little learning takes place. For example, one or more partners may feel compelled to do more than their normal share of the work either by choice (giving other members a "free ride") or by default (being manipulated into playing "the sucker"). Partly because of the variability of results, many researchers today agree that collaborative arrangements are no guarantee that learning will be efficient; there are simply too many factors affecting the process. For that reason, most research no longer seeks evidence that collaborative learning is efficient, but instead looks into the conditions favorable for collaborative learning or the types of interactions that characterize successful collaboration (Dillenbourg et al., 1996).

The question remains, however, as to how a researcher can know whether a particular collaborative effort is successful, especially one involving a long-term project in the workplace (Dillenbourg et al., 1996). What does successful collaboration mean? Conceivably, a project team may have productive collaborative relations, but because of the complexity of the problem or adverse environmental conditions, the team may still fail to reach an acceptable solution. The current study proposes that participants themselves can indicate whether their collaboration was productive by reporting (via a questionnaire) their *satisfaction* with or positive attitudes toward the cognitive and communicative aspects of their project, both at the individual and group levels. This technique for assessing collaborative activity is discussed in Chapter 3.

CONDITIONS FOR COLLABORATIVE PROBLEM SOLVING

The range of conditions affecting interactions between team members is almost limitless, and many can have a telling effect on the cognitive and social aspects of a project. For example, a few studies have examined group size (dyad, triad, quad, and larger numbers) as a single factor influencing interaction and learning (Webb & Palincsar, 1996). Those studies have shown that the optimal size of a group depends on environmental resources and the types of media in which the problem can be represented. For instance, only small groups can be expected to benefit from work at a single keyboard and personal computer screen. Some research shows that triads tend to be more competitive than pairs, while pairs are comparatively more cooperative (Trowbridge, 1987). Other research finds that members of two- and three-person teams interact similarly, while Webb (1984) and Webb, Ender, and Lewis (1986) suggest that students in triads may be prone to ignore teammates' questions (Webb, 1984; Webb, Ender, & Lewis, 1986). Likewise, Webb et al. (1996) observes that group sizes of four or more make it easier for members to avoid having to answer questions (Webb & Palincsar, 1996). In short, differences in group sizes seem to involve a number of different types of trade-offs.

Besides group size, other conditions affecting collaboration include group incentive structures, differences in member ethnic backgrounds, language proficiency, socioeconomic status, and gender (see Webb & Palincsar, 1996, p. 859ff, for a review of the classroom research on most of these factors). Because the source of most research data on conditions is the classroom, further study is necessary on whether the conditions have the same effects on adult peer engineers collaborating on real-world problems, or whether there are yet other conditions affecting engineering teams that are beyond the observational limits of classroom-based research.

This study takes into account three conditions that intuitively seem to have a general affect on the type and quality of collaborative interactions that appear in discourse.

These conditions include the nature of the problem or task, distribution of knowledge and expertise within the group, and differences in attitudes toward the cognitive and social aspects of engineering task activities (Dillenbourg et al., 1996; Slavin, 1996; Webb & Palincsar, 1996). These conditions for collaborative interactions are described below.

Nature and Length of Task

Because design activity encompasses many different but coordinated subtasks (Goel & Pirolli, 1989, 1992), a plausible assumption is that some subtasks lend themselves more easily to collaboration than do other subtasks. There is little systematic research on how different types of tasks influence group processes (Webb & Palincsar, 1996), but a few studies in classroom teaching/learning have identified problem factors that may affect interactions. Those include the amount of conceptual knowledge the given task requires (Damon & Phelps, 1989), the social skills for negotiating interactions (E. Cohen, 1994), and the degree that the task requires contributions from all members in the group (Steiner, 1972). Also important is whether the task lends itself to a division of labor (Hertz-Lazarowitz, 1992; Hertz-Lazarowitz, Kirkus, & Miller, 1992).

To some degree, the nature of the problem (and the pattern of interactions) depends on how the group decides to go about solving it. It is well known that different teams solving the same problem may adopt different patterns of interaction (Bos, 1937; Forman & Cazden, 1985; Resnick et al., 1993; Saloman, 1993a). For example, Forman and Cazden (1985) found that student pairs (9 years old), all attempting to solve a problem, employed different styles of working together. Some adopted parallel procedural interactions: they exchanged comments about the task, but did not monitor each other's efforts or attempt to share their reasoning. Some adopted associative interactions: they exchanged comments about what the other was doing, but made no attempt to coordinate their activities. The third and most successful student pairs adopted cooperative procedural interactions: they not only monitored each other's activities but coordinated their roles to complement each other's efforts.

Forman and Cazden's findings were based on observations of students solving well-defined Piagetian isolation-of-variable problems. Many types of tasks, however, are "inherently distributed" (Dillenbourg & Schneider, 1995, p. 16); that is, team members may work effectively apart from one another and assemble their results later, or they may coordinate their work by following established procedures or strategically ordered sequences of operations. Examples of naturally distributed tasks that have been studied include navigation aboard large ships (Hutchins, 2000), engineering practices (Rogers, 1992; Rogers & Ellis, 1994), air traffic control (Halverson, 1995), and an airplane's cockpit operations (Hutchins & Klausen, 1996). Typically, members of these groups work in close cooperation, and the work itself is carefully sequenced. Results from one action are delivered by some medium for further processing in the next step of the procedure. In such activity and cognitive systems, the relationships between individuals are stable and persistent (Nardi, 1996).

In situations where predetermined problem-solving procedures are not available—when the problem itself is poorly defined and applicable knowledge has not been identified or appears contradictory—the applicability of the distributed perspective may not be so immediately clear (Perry, 1997) For example, planning and definitional tasks and other "semantically rich" phases of projects entail more exploratory discourse, negotiation, and information sharing as team members attempt to build a common ground of understanding and to devise ways of coordinating their problem solving efforts. At those times, conditions may be more favorable for co-constructive forms of knowledge building (Dillenbourg & Schneider, 1995).

The length and complexity of the problem-solving process may have particular effects on the organization and procedures set up by the participants. Unfortunately, most studies of collaborative problem solving involve participants attempting to solve well-defined problems that require about an hour's work in carefully controlled experimental conditions (Doise & Mugny, 1984; Webb, 1991; Webb et al., 1995). This empirical approach, while useful in child-development studies, is poorly suited for investigations into the social practices that develop over long-term collaboration.

There are several good reasons for observing longer-term problem solving, most related to the increased importance of metacognitive and team-regulatory behaviors that emerge as the problem complexity increases. The following are a few of those reasons.

First, longer-term observations reveal not only how partners interact, but also how their interactions grow into working relationships (Hinde, 1979). Relationships, in most cases, give a wider view of how partners build on their commonalities and work out their differences to good advantage. Moreover, longer-term problems give time for the problem-solving properties of the participants to reveal themselves.

Second, problems complex enough to require days, weeks, or months to solve also require considerable coordination among the problem solvers (Barron, 2000). Good problem solvers may not be good coordinators, and when a team is considered holistically and over time, good coordinators may be as much a part of the solution as good problem solvers. Skills in coordination, interpersonal relations, and management are qualities often squeezed out of studies of short-duration problem solving.

Third, prolonged engagement allows time for the team members to gain knowledge about their partners (for example, to know what their partners know) so that they can predict their partners' responses and attitudes (Clark & Schaefer, 1987). While short-duration problem solving reveals partners' efforts to align their thinking at the utterance level, prolonged complex-problem solving involves more complex alignment activities involving whole sequences of interactions (Baker, 2002; Barron, 2000).

Fourth, past interactions prepare for future interactions, because all past interactions reside in the shared memory of the participants (Rogoff, 1998) and make up part of the common knowledge (Simon & Lea, 1974). Responses in some interactions that puzzle the researcher may have their explanation in previous, unobserved interactions.

Fifth, complex problems in the workplace are rarely of one type; they often decompose into lesser problems of various types: definition, analysis, trial-and-error, and so on (Ancona & Caldwell, 1990; Ball, Evans, & Dennis, 1994; Goel & Pirolli, 1992; Pea, 1993b; Polya, 1957). Difficulties at the local level can expand into problems in their own right. This complexity often leads to ad hoc divisions of labor as the project proceeds, so that eventually different types of domain knowledge settle upon particular group members, and thus not all interactions can be collaborative. At times, even, more skilled team members must support or acquiesce to less skilled partners during some interactions.

Distribution of Knowledge/Expertise

Peer differences in domain knowledge or skills have received considerable attention in the empirical research related to the theories of Piaget and Vygotsky. Piaget's position is that, by working with peers (those whose knowledge and developmental level are symmetrical but who may differ in viewpoints), children encounter perspectives that conflict with their own. This difference creates in the lower-ability child a disequilibrium that compels the child to adjust to the new way of viewing an issue. In contrast, Vygotsky argued that collaborative learning requires partners whose skills are asymmetrical, as can be expected between an adult and a child (Vygotsky, 1978; Wertsch, 1985). As Dillenbourg states, these theoretical differences are difficult to compare empirically, because they involve conceptually different definitions of expertise (Dillenbourg et al., 1996).

Empirical studies involving Piagetian conservation problems generally show improvements in the performance of low-ability students when they are working with high-ability partners (for example, Bell, Grossen, & Perret-Clermont, 1985; Doise & Mugny, 1984). Research on other types of tasks have also shown that low-ability students benefit from working with more skilled partners of various numbers (for example, Azmitia, 1988; Tudge & Rogoff, 1989; Webb, 1980. Also see Webb & Palincsar, 1996). Those and other empirical studies (for example, Hooper & Hannafin, 1988; Hooper, Ward, Han-

Hannafin, & Clark, 1989) also indicate that high-ability students benefit from working with less able partners, and in fact one researcher described a case in which high-ability students learned more in heterogeneous groups than in homogeneous groups (Webb, 1980; Webb & Palincsar, 1996). As most of the authors of those studies agree, however, whether a low- or high-ability student benefits from collaboration depends on how much explanation, demonstration, and reasoning are exchanged during the joint efforts.

Webb (1996) reviews several studies indicating that mutual perceptions of partners' abilities play an important role in team participation (E Cohen, Lotan, & Catanzarite, 1990; Dembo & McAuliffe, 1987; Webb, 1984). There is evidence that when partners sense that the other group members have attributed to them more expertise than they actually have, they may respond positively to that greater expectation by volunteering more explanations and initiating more exploration into alternatives. For example, Dembo and McAuliffe (1987) gave fictitious scores to students on a pretest, and when the students were assigned to heterogeneous groups based on those scores, the "more able" students were more likely to offer to assist the "less able" students (Webb & Palincsar, 1996). Little research is available, however, as to whether the effects of perceived differences persist over long-term projects. Verba and Winykamen studied the relationship between interaction type and two types of expertise: general ability and domain-specific expertise (Verba & Winnykamen, 1992). When the high-ability partner was also the domain expert, the interactions consisted of tutoring and scaffolding. When the lower-ability student was the domain expert, however, the interactions were more collaborative and co-constructive.

In summary, most educational studies show that, in heterogeneous groups, low-ability students are likely to benefit from the assistance they receive and that high-ability students may benefit from their explanatory and exploratory roles (Webb & Palincsar, 1996). Middle-ability students in larger groups (those that include low-, middle-, and high-ability students) represent a more problematical category, for they may be excluded from the mutually rewarding interactions between the low- and high-ability students. In a review of such studies, Webb (1991) concluded that the achievement of middle-ability students is generally greater when they participate in homogeneous groups. In all cases, however, whether students benefit from collaborative work depends largely on their availing themselves of the opportunities for help, exploration, and sharing. As Dillenbourg (1996) and many other researchers stress, there is no way to determine that they will. In engineering teamwork, domain knowledge is of course essential, and that, along with the ability to articulate that knowledge, is an essential component to what Pea calls competence (Pea, 1993a).

In terms of collaborative problem-solving interactions, however, the more knowledgeable person does not necessarily unilaterally set the direction and focus of team discourse. A partner may have less domain knowledge, but nevertheless have a more global view of overall procedures and goals. This less knowledgeable partner may still be able to initiate topics that refocus the discourse to take in a wider range of considerations. As Miyake says, "In two-person, constructive interactions, the person who has more to say about the current topic takes the task-doer's role, while the other becomes an observer monitoring the situation. The observer can contribute by criticizing and giving topicdivergent motions, which are not the primary role of the task-doer" (Miyaki, 1986, p. 174). In longer projects especially, when the coordination of team activities becomes more complex and necessary, the functions of project monitor or manager may be critical to project success.

Differences in Engineering Task Preferences

Researchers recognize that complex, ill-defined problems require efforts not only to generate a solution (product), but also to coordinate the efforts toward a solution (process) (Barron, 2000; Dillenbourg et al., 1996; Hogan et al., 2000). The way team partners respond to product- and process-focused activities may differ, and for different reasons. For example, a partner may realize more clearly than other partners that his or her own aims can be met only if the group itself succeeds (Johnson & Johnson, 1992; Slavin, 1996), and that person may be more willing to devote energies to maintaining productive working relations (Slavin, 1995). Partners who are more absorbed in the technical details of the project (Csikszentmihalyi, 1996) may be relieved that the more globally motivated partner is staying alert to group conditions and resources. Issues of self-identity as an engineer may be involved (Lave & Wenger, 1991): for some individuals, a role as coordinator or facilitator reinforces their sense of membership in a community of engineers. Some persons are simply more affiliative than others; they want and strive for friendly relations among their partners (Ormrod, 1999).

The current study proposes that collaboration requires that group members have some parity of input at both the product and process level of problem solving. If partners are divided in their preferences for task types, however, then an interesting question would be how they adjust their interactional roles and cooperative arrangements to keep their contributions in balance. Those adjustments should show up in the ways the partners share the cognitive load in their conversations regarding product versus process topics. Chapter 3 will describe procedures to address that question.

INTERACTIONS AND GROUP LEARNING

The various conditions affecting cooperative work can be expected to interact, which enormously complicates efforts to isolate and analyze the effects of any single factor (Webb & Palincsar, 1996). Several researchers, therefore, have stressed the importance of studying the structures of productive conversations and cooperative forms and then identifying the factors that render them productive (Barron, 2000; Resnick et al., 1993). Likewise, Dillenbourg (1996) stresses the need to identify intermediate variables that not only describe interactions but can also be related to conditions and outcomes.

Whereas the Piagetian and Vygotskian perspectives may be too global to explain results at the interactional level (Mandl & Renkl, 1992), the distributed-cognition perspective, which takes as its unit of analysis the functional system, places emphasis on understanding conversational structures—or social learning mechanisms—that improve the knowledge state or problem-solving capacity of the group, instead of localizing the problem-solving improvements in the minds of the individual group members (Rogers & Scaife, 1997). This emphasis is in keeping with the main contentions of distributed cognition that systems think differently from individuals (Hutchins, 2000) and that adaptations in the system occur via the interactions among the individuals (and artifacts) composing the system (Rogers & Scaife, 1997). In addition, a change in focus from effects and conditions to conversational structures of interactions suggests an expansion of research methods to include ethnographic and pragmatic observational techniques (Dillenbourg et al., 1996). The value of these methodologies is that they tend to show *why* and *how* certain group outcomes appear.

The interactions of interest in this study are those that in some wau embed or entail learning mechanisms; that is, both participants (or even bystanders) experience cognitive change, which is in keeping with sociocultural theory (Rogoff, 1998). Such mechanisms, for example, are (self-)explanation, conflict resolution and argumentation, and co-construction. Each of these processes requires that partners achieve some degree of intersubjectivity and makes use of transactional dialogue, that is, discussions in which each person's reasoning actuates his or her partner's reasoning and vice versa (Azmitia & Montgomery, 1993; Berkowitz & Gibbs, 1985). Some of these social learning mechanisms are described below.

(Self-) Explanation

All of the theoretical perspectives discussed in Chapter 1 emphasize the importance of communication between problem-solving partners (Coleman, 1989). Several studies have shown the positive effects of explanations on the interlocutors' understanding of scientific facts (for example, Dreyfus, Jungwirth, & Eliovitch, 1990; Driver, 1987). In addition, "explanation-seeking efforts" seem to correlate well with achievement (Chi, de Leeuw, Chiu, & LaVAncher, 1994; Coleman, 1989, 1995; Coleman, Brown, & Rivkin, 1997). Several studies have also examined the nature of peers' verbal contributions during explanation, patterns of question-asking, and their relation to achievement (Coleman, 1989, 1995; Coleman et al., 1997; Crook, 1995; Hatano & Inagaki, 1991; Webb, 1991). Chi et al. (1989) showed that students, asked to explain aloud the solution of previously solved physics problems, were able to strengthen their declarative knowledge of solution procedures, make their tacit understandings of the problem explicit, and improve their ability to solve similar problems (Chi et al., 1989).

The research indicates that explanation creates conditions for collaborative interactions that benefit both the explainer and the listener, as long as the explanation involves some degree of elaboration (see Webb, 1991) for a review). Elaborated explanation reveals the procedural details and underlying reasoning of ongoing problem solving, whereas non-elaborated explanation provides answers unaccompanied by reasoning. Elaboration requires that explainers reorganize their knowledge according to their listeners' level of understanding. This restructuring process may bring to light inconsistencies or "fuzzy" areas in thinking and forces the explainer to rethink their knowledge from different perspectives (Webb & Palincsar, 1996). Moreover, the act of verbalizing previously unspoken and unexamined ideas and assumptions tests one's knowledge against those of the listeners, in which case feedback (for example, further elaboration or counter-claims) becomes an important part of the interaction. In addition, by "talking science" or engineering (Lemke, 1990), explainers quicken their access to information stored in memory and improve their facility for mentally manipulating the facts (Yackel, Cobb, & Wood, 1991). Webb and Palincsar (1996) and Rogoff (1998) suggest that explanations to a peer has more of an exploratory quality, generates more analytical perspectives, and induces deeper conceptual change than explanations to an expert, which are frequently used to demonstrate mastery of the material (see also Durling & Schick, 1976). At the same time, the receivers of explanations acquire new information, build new associations, and see farther into the thinking and intentions of their peers (Webb & Palincsar, 1996).

Cognitive Conflict and Argumentation

As discussed in Chapter 1, the sociocognitive perspective on learning values cognitive conflict as a process by which individual learners restructure their views to be in line with events they observe in the real world (Doise & Mugny, 1984). Though the original formulation of cognitive conflict treated the change itself as taking place in the individual's head and was therefore individual centered, Doise and Mugny (1984) extended the application of the principle to social interactions, that is, occasions when a discrepancy between views causes overt conflict or controversy (Baker, 1998; Dillenbourg, 1999a; Webb & Palincsar, 1996). Such differences in opinion may cause individuals to question their own positions and re-examine their suppositions; they may seek additional evidence to support their position or to resolve the disagreement; or they may find they have to yield to a more convincing argument. As Webb and Palincsar (1996) observe, all those processes are integral to learning.

While a moderate degree of conflict may be productive, too much or too little conflict may have deleterious effects on learning (Brown & Palincsar, 1989). Too much controversy can raise distracting personality issues, reduce one's receptivity to new interpretations, and curtail objective appraisal of an issue and the various positions taken toward it. Too little conflict may be a sign that the team's decision-making has succumbed to groupthink (Janis, 1982), in which extreme social pressures on the group members to maintain unanimity prevents them from voicing their own opinions or from challenging the opinions of others. The suppression of disagreement may also be a sign that one or two members are dominating the others. Such social conditions undermine the decision-making potential of the group and may produce little more than "pseudo-agreement" that belies the true thinking of the group members.

At its best, argumentation can constitute a powerful decision-making routine. Through argumentation, the team members in effect rigorously screen new propositions before they admit the propositions to or remove them from the team's common ground of understanding (Baker, 1998). The members produce evidence, defend claims, define warrants, verify facts, and clarify positions. These processes also may expose weaknesses or incompatibilities in propositions already tentatively accepted, so that even old information is continually tested against the new.

Finally, argumentation may help team members circumvent the "confirmation bias," that is, the tendency to interpret data or design experiments to confirm currently held hypotheses and to ignore or depreciate contradictory evidence (Dillenbourg & Schneider, 1995; Hutchins, 2000). In other words, unless shown differently, people tend to "see" only evidence that bears out their current belief systems. Confirmation bias may arise, for example, whenever decision makers have no alternative hypothesis. By supplying that alternative hypothesis, namely, the position taken by another team member, a member willing to question or offer a counter-explanation prevents the group from totally disregarding of other possibilities available to the problem-solving process.

Co-Construction

In sociocultural theories, co-construction is the process by which peers take complementary roles or take turns assuming the same roles to construct knowledge beyond the ability of each peer to supply individually. For example, one partner may make a proposal to which the second partner responds and offers a counterproposal or elaboration, to which the first partner responds, and so on (Baker, 2002), so that the problem-solving process spirals upward from the contributions of both partners. Neither peer is "more capable" than the other (Forman & Cazden, 1985, p. 343). Forman and Cazden (1985) observed co-constructive problem-solving behaviors in 9-year-old children solving chemistry problems in pairs. In one pair especially, one child would perform operations while the other provided essential corrections, channeled the direction of the effort, and offered encouragement and support. This cooperative behavior, which was most prominent during the setting-up phase of the experimental task, resembles the scaffolding techniques by which an adult/expert ably guides a child/novice (Wood et al., 1976). Later in the tasks, during the analysis of results, the children tended to reach independent interpretations. It was only then that the interactions assumed the characteristics of conflict resolution and argumentation.

Planning tasks also figured in Gauvain and Rogoff (1989). These researchers compared errand-planning performance among 5-year-olds working alone, with peers, and with adults (Gauvain & Rogoff, 1989). The authors found that for the children to improve planning skills working with a partner was not enough; the child also had to share fully in the planning responsibilities of the task. Moreover, the study showed that by exercising their share of the responsibility the children were more involved in developing metacognitive strategies.

Other Group Learning Mechanisms

Research in pragmatics and shared, or distributed, cognition have drawn attention to three other social mechanisms that relate to the problem-solving capability of a group (Dillenbourg & Schneider, 1995). They are shared cognitive load, mutual regulation, and social grounding. These important mechanisms are not independent from but operate in conjunction with the previous mechanisms.

Sharing the Cognitive Load

The descriptions of the three previous social mechanisms—(self-) explanation, cognitive conflict and argumentation, and co-construction—imply that there are certain roles that a partner can assume relative to the other partner, roles such as proposer, explainer, critiquer, and so on. Dillenbourg and Schneider (1995) refer to this spontaneous breakout of conversational roles as a sharing of the cognitive load. For example, a more knowledgeable partner may become by tacit and mutual consent the task-explainer, while the other partner becomes the monitor and commentator (Miyaki, 1986). Situationally, the person who holds the mouse at a computer usually takes the initiative in deciding which operations to perform and thus which topics to discuss. The effect of this spontaneous distribution and redistribution of the cognitive burden is to eliminate redundancy in the cognitive system and to increase efficiency by allocating intellectual resources optimally among smaller cognitive functions (Dillenbourg et al., 1996). It may also be a device for matching types of contributions to the partner recognized as best qualified for making them.

Mutual Regulation

At intervals in the various types of collaborative interchanges (argumentation, elaborated explanation, and so on), team members are compelled to divulge the underlying strategies or heuristics behind their reasoning (Dillenbourg & Schneider, 1995). Such divulgences, whether requested or freely given, not only give the partners useful insight into what each is thinking, but they also regulate the thinking of the whole group. Partners, for instance, may be less likely to insist on or agree to a proposal that they cannot justify or explicate to the satisfaction of another, and they are more inclined to promote ideas for which they can muster a defense.

Social Grounding, Joint Problem Space, and Negotiation

To Clark and his colleagues (Clark & Brennan, 1991; Clark & Schaefer, 1987; Clark & Wilkes-Gibb, 1986), conversation itself, like all collective actions, is a collaborative enterprise built upon a common ground of shared knowledge, beliefs, and assumptions (Clark & Schaefer, 1987). The moment-by-moment conversational process of updating the common ground is called *grounding*. To add a contribution to the common ground, however, both the speaker and the listener must feel confident that the speaker has been sufficiently understood by the listener. Consequently, grounding requires that the partners be alert to positive and negative evidence that their message has or has not been correctly received. (Clark & Wilkes-Gibb, 1986; also Sacks, Schegloff, & Jefferson, 1974; Schegloff et al., 1977). This process involves alignment practices, which are various uses of "talk . . . to frame messages for purposes of clarifying, interpreting, and managing conversational meaning and communicator roles" (Ragan, 1983, p. 159). The listener, for example, may indicate that he or she has understood by overtly acknowledging the contribution, initiating a next turn that is relevant, or displaying continued interest and attention (Clark & Brennan, 1991). Grounding does not require that the partners understand each other perfectly. In the words of Clark and Schaefer, "The contributor and his or her partners mutually believe that the partners have understood what the contributor meant to a criterion sufficient for current purposes. This is called the grounding criterion" (Clark & Schaefer, 1987, p. 129).

The grounding criterion represents a contrast with Grice's more prescriptive Cooperative Principles. For example, Grice states that proper utterances in a conversation should be no more informative than they have to be and should be spoken in a manner appropriate to the listener and situation (Grice, 1975). Clark, however, suggests that Grice's principles are aimed at "flawless presentations and trouble-free acceptances," which may be impossible to produce in difficult problem-solving conversations (Clark & Brennan, 1991, p. 134). Problem-solving conversations are usually subject to constraints such as time pressures, errors in reference and expression, and ignorance of the interlocutor's knowledge and understanding (Clark & Wilkes-Gibb, 1986). Clark prefers to think that, rather than attempt to minimize the amount of effort they put into producing single utterances, partners seek to minimize the amount of collaboration required to make an utterance mutually understood (Clark & Brennan, 1991). This principle of least collaborative effort may explain why speakers prefer to repair their own utterances rather than let their partners do so, as Schegloff et al. (1977) demonstrate. On the other hand, persons working together in unfamiliar knowledge domains may discover that they have to expend more effort to put an elusive thought into clear expression than to offer a provisional utterance in the hope that the partner will complete, repair, or carry the inchoate thought forward (Clark & Brennan, 1991; Clark & Wilkes-Gibb, 1986). In those ways, grounding efforts to establish mutual understandings can lead to learning by both partners even though—or because—the conversational turns are less than perfectly communicative.

Common ground has its origins in the study of everyday conversations. Rochelle and Teasley, however, have expanded the concept of common ground to apply specifically to socially organized problem solving (Roschelle & Teasley, 1991). In doing so, they have combined the construct of common ground with what they call a joint problem space. A joint problem space is “a shared knowledge structure that supports problem solving activity by integrating goals, descriptions of the current problem state, awareness of the available problem-solving actions, and associations that relate goals, features of the current problems state, and available actions” (Roschelle & Teasley, 1991, p. 70). In effect, the joint problem space is the common-ground construct from the cognitive perspective. Its construction requires that partners introduce and accept which items of knowledge to include in the space, monitor on-going activity for its compatibility with what is already known, and repair misalignments in understanding that cripple interaction. Like common ground, the joint problem space is built through ordinary conversational structures of alignment. Roschelle and Teasly, for instance, mention the flow of turn-taking, collaborative completions of turns, repairs, and narrations (Roschelle & Teasley, 1991) as important processes in maintaining the joint problem space. The construction of joint problem space, moreover, also makes use of extended discourse structures such as argumentation, explanation, and co-construction as examples of efforts to build a joint solution of the problem.

In collaborative problem solving, the interlocutors must eventually agree or accede to partial and final solutions based on their common ground of understandings (Baker, 1994). In problem-solving discourse, agreement/acceptance of a problem solution may perhaps be regarded as the goal of each interaction and the collaboration in general (as distinct from the cognitive goal, which is the problem solution itself). This imperative to reach agreement (or to gain acceptance) requires that the collaborators negotiate meanings and issues when they diverge in their thinking. Negotiation is used here in two senses: not only does it refer to the interactional practices by which partners agree to the meanings of their symbolic productions (Pea, 1993a), it also refers to the everyday use of conversational structures such as argument and explanation to reconcile two competing viewpoints or goals (Baker, 1994). In these terms, negotiation embraces all the group processes discussed previously, but with the added consideration of local agreement as the intent for those processes.

APPROACHES TO DESCRIBING PROBLEM-SOLVING INTERACTIONS

A major issue in the study of interactions in long-term problem-solving discourse is the choice of analytical units. Major theoretical studies refer to interactions repeatedly, but never define what an interaction is (for example, Lave & Wenger, 1991). Among discourse analysts (for example, Clark, 1996), interactions are seen to be "dynamic and transactional and the 'context' is a co-construction of participants in a social situation on a moment-to-moment basis" (Barron, 2000, p. 435). Clark (1996) uses the term *ensembles*, which emphasizes that conversations are joint constructions, with the participants mutually creating "possibilities for one another as they interact" (Barron, 2000, p. 406). Hogan et al. (2000) refers to *interaction sequences*, which are "units of dialogue" that begin when a speaker makes a conceptual or metacognitive statement or poses a question or query, continues through the reply or reaction from at least one other person, and ends when "a speaker steps back from the flow of the interaction" (Hogan et al., 2000, p. 390).

Hinde (1979), recognizing the arbitrariness in what we call an interaction in daily life, set certain constraints on its definition. Accordingly, an interaction must involve both partners, the behaviors involved in the interaction must relate to meanings contained in the interaction, and, in addition to meaning (content), an interaction must have "quality" (Hinde, 1979), which Hinde does not clearly define, but in problem-solving conversations perhaps *quality* can be interpreted to refer to the degree of change an interaction brings about on the mutual understanding between the participants. In addition, Hinde says that any description of a relationship must include reference to the content, quality, and *patterning* of interactions (p. 20).

Categories of Interactions

Another empirical issue is a question of categorization. In what ways can interactions in problem-solving discourse be classified? Dillenbourg et al. (1996) identify three "oppositions," or discriminations, that appear in the literature. First is cognitive versus social: the interaction is either directed at the problem (cognitive) or is has some other intent (social). Second is cognitive versus metacognitive: the interaction is either indistinguishable from the problem-solving process, or it is affiliated in some way with the problem solving process, or it is both. The third is task versus communicative: the interaction is task oriented when the participants are negotiating or co-constructing solutions, and the interaction is communicatively oriented when the participants are "establishing common referents" and exchanging commentaries and evaluations (Dillenbourg et al., 1996; also see Barbieri & Light, 1992). A difficulty with the cognitive-metacognitive and the task-communicative dichotomies is that at times utterances seem to be both. For example, as Dillenbourg et al. (1996) point out, a speaker may contribute to the task at hand and at the same time reveal to the listener that both are sharing the same focus.

A number of researchers in education and computer-assisted cooperative work have combined strategies for observing and analyzing group problem solving interactions (for example, Baker, 2002; Barron, 2000; Dillenbourg, 1999a, 1999b; Hogan et al., 2000). Barron (2000), for instance, in a case study involving two problem-solving triads (sixth-grade boys) working on a problem posed in an adventure video, examined the transcripts of the teams' problem-solving dialogue for three properties: articulation of solutions, repetitions of proposals, and responses to proposals. Responses to proposals included acceptances, elaborations, clarifications, rejections, and the absence of a response. In this study, Barron tried to discover the general features of problem-solving interaction that contributed to the coordination of team activities, as well as "the particularities of the two groups' trajectories of interaction" (p. 409). Using a quantitative approach to discern the patterns in the discourse and a qualitative description of critical events in the teams' problem-solving efforts, Barron was able to show that the more successful group distinguished itself not only in problem-solution outcome but also in the efficiency in which the group coordinated their activities. Specifically, Barron identified three conditions for effective group coordination: mutuality of exchanges between members, degree of joint attention, and degree of alignment of goals.

Hogan et al. (2000) related patterns of interaction with reasoning complexity in the discourse of four triadic groups of eighth-grade science students as the students attempted to construct mental models of the composition of matter. The researchers analyzed the discourse at multiple levels: individual statements (coded as conceptual, metacognitive, and question-query), conversational turns (coded as knowledge construction, logistical, or off-task topics), interaction sequences (coded as consensual, responsive, or elaborative), and so on. The researchers compared the discourse patterns of peer discussions with patterns from teacher-guided discussions and found that the teacher-guided discussions more effectively prompted students to articulate their thinking and expand their understanding. Peer discussions, however, were more generative and exploratory. This study is notable in that it combined analysis at three levels: utterances, episodes (divisions of discourse on the same general topic and purpose), and interactions.

Interactional Dimensions: Symmetry, Alignment, and Agreement

Baker (2002) proposes a simple but effective model for describing problem solving interactions and relating them to cooperative forms and learning processes. Baker proposes that any given purposeful interaction has —to varying degrees—each of the following qualities: symmetry, alignment, and agreement/acceptance.

- Symmetry is the degree to which the interlocutors share or exchange transactional roles during the interaction, that is, the degree that the conversational contributions of both partners contribute to aspects of the problem-solving task. Examples of roles are Proposer, Responder, Critiquer, Explainer/Justifier, Implementer, and Regulator. If the two partners alternate in the role of Proposer or Elaborator, for example, then they are building on each other's contributions and the interactional sequence is symmetrical. If one team member consistently exercises the role of Proposer, while the other takes the role of Responder, then the interactional sequence is asymmetrical because the Proposer role generates more new information than the Responder role (Baker, 2002).

- Alignment refers to the degree with which the partners are genuinely working together. Partners may be out of alignment in their understandings of the problem or their interpretations of where they stand in regard to a solution. A completely misaligned interaction is one in which the partners are talking at cross-purposes. Closely related to alignment is grounding, or the partners' joint attempt to build and maintain a shared problem-representation (Baker, 2002). Note that this use of the word alignment is different from that in conversational analysis, where alignment refers to attempts at the utterance level to "frame messages for purposes of clarifying, interpreting, and managing conversational meaning and communicator roles" (Ragan, 1983, p. 159).

- Agreement/acceptance refers to the degree that the partners express that their attitudes toward propositions under joint consideration are alike. Agreement is treated here as the absence of open disagreement, and the interaction may take a number of cooperative forms and still end with agreement. Disagreement, however, is associated only with interaction characterized as argumentative (Baker, 2002).

These dimensions make useful keys for determining types of cooperative forms, as discussed in the following.

Cooperative Forms

Each of the dimensions represents a continuum (for example, from symmetrical to asymmetrical), and when configured together they identify four cooperative forms as follows (see Baker, 2002, p. 7).

- Co-Construction: The interaction is symmetrical and aligned, and the partners agree. Both partners build on the knowledge supplied by the other.

- Co-Argumentation (or Two-Sided Argumentation): The interaction is symmetrical and aligned, and the partners do not agree. Both partners propose and defend.

- Acquiescent Co-Elaboration: The interaction is asymmetrical (only one partner proposes while the other provides feedback, verifies, encourages, etc.) and aligned. The partners agree.

- One-Sided Argumentation: The interaction is asymmetrical and aligned, and the partners do not agree.

Note that in each of the four cooperative forms above the partners are aligned. If, all else being equal, the partners are not aligned in a given cooperative form, then that form is only its "apparent" counterpart. For example, Apparent Acquiescent Co-Elaboration would describe an interaction in which one partner offers a proposal, to which the other partner responds without an understanding of the meaning of the proposal, or the first partner may not understand the response he or she receives from the second.

Baker's interactional model, comprising the interactional dimensions and the co-operative forms, represents a particularly useful analytical tool for any study (such as this one) that seeks to describe interactions between partners who may differ in cognitive and communicative parameters. More about how Baker's model will be used in this study is given in Chapter 3.

CONCLUSION

This chapter has reviewed representative research on the effects of collaboration, the conditions for successful interaction, and types of group processes and cooperative forms. In addition, the chapter has described some analytical approaches to the study of collaborative interaction. The current study adds to that research in three ways. First it introduces a new condition to interaction, namely, the differences between collaborators in their preference for cognitive or socially oriented tasks. Second, for a measure of outcome to collaborative problem solving, the study introduces satisfaction—the participant's satisfaction with the cognitive and social/communicative aspects of a design project—as an indicator of the quality of collaboration. The next chapter will describe the design and methodology of this study.

CHAPTER 3
METHODOLOGY

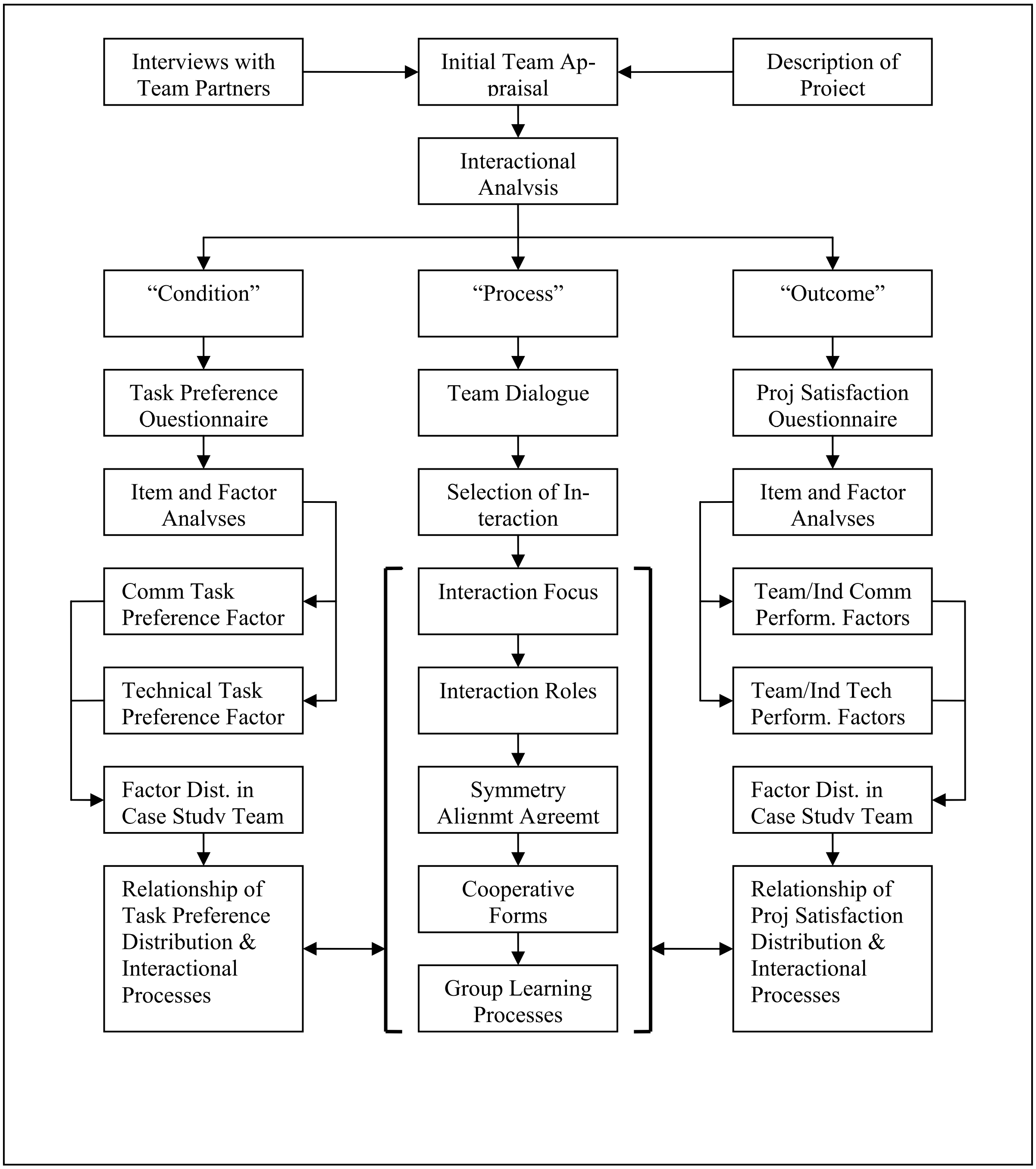
This study develops a framework for describing problem-solving interactions and applies that framework to interactional analyses of three dyadic teams of senior-level student electrical and computer engineers at a large university in the U.S. Southwest who are engaged in long-term design projects. The three examples draw on data from questionnaires and transcriptions of team dialogue. After providing an overview of the study design, this chapter describes the quantitative and qualitative methods for gathering and analyzing data and the generation of the descriptive framework.

OVERVIEW OF THE INTERACTIONAL FRAMEWORK AND ITS APPLICATIONS

The interactional framework developed in this study is shown in Table 3-1, and examples of its applications to actual discourse data are given in Chapter 5. Each application study begins with a brief summary of the design problem a team is trying to solve. The study then presents excerpts from interviews in which the team members speak frankly of their team's progress and their working relationship. These first-person remarks and observations give a flavor of the participants' personalities as well as an insider's view of the project operations.

Next the application study reviews the results of the questionnaire surveys and the engineer profiles for the team partners (the "Condition" and "Outcome" portions of Table 3-1. The profiles are consolidations of information from the questionnaires that simplify

TABLE 3-1
A FRAMEWORK FOR DESCRIBING PROBLEM-SOLVING INTERACTIONS



the comparison of team members.) The study compares first the team members' scores on the Engineering Task Preference Questionnaire and its associated engineer profile, and then the scores on the Project Satisfaction Questionnaire and its engineer profile. Emphasis in the examination of the quantitative data is on identifying differences in partners' attitudes toward cognitive and communicative aspects of engineering work in general and those same aspects regarding their actual project performance. Knowledge of those differences (and similarities), in turn, may help in determining why the partners take the roles they do during team problem-solving interactions.

The application study then analyzes a number of team interactions during the early stages of the project (the "Process" portion of Table 3-1), a time when the partners are becoming familiar not only with the problem and project procedures but also with each other. The interactions selected are those that seem to typify the cooperative discourse of the two partners or otherwise bring out the character of their relationship. Within each interactional sequence, the study identifies the conversational roles of each team member and determines how the interplay of those roles forms patterns recognized by Baker as cooperative forms (see Chapter 3). Examples of such forms are Co-Construction and Co-Elaboration (Baker, 2002). Some of those cooperative forms, in turn, can be related to group-level learning processes, such as conflict resolution and (self-) explanation, that increase the overall capacity of the team as a problem-solving system.

Each application study concludes with a holistic and interpretive look at the given design team as a coherent problem-solving unit. This broad perspective incorporates the contrastive data from the questionnaires and profiles, insights from the interviews, and the observations from the interactional analysis. The aim is to show how, despite or because of their unique configurations of differences, the team members manage to navigate a path toward a problem solution, or fail to, as the case may.

The third application study is handled a little differently from the other two. In that example, an attempt is made to interpret or describe team interactions on the basis of the profile and interactional data alone (forgoing the use of interview and item-by-item questionnaire data). This abbreviated approach is taken to demonstrate the most parsimonious use of the descriptive framework.

In addition to demonstrations of framework in use, a survey is taken of engineering students working on collaborative projects to determine when in a project collaborative discourse is most intense.

Collection and Processing of Conditional and Outcome Data

Questionnaire surveys were used to identify factors that can help in the interpretation of interactional conditions and outcomes. Three questionnaires were administered to a sample of engineering students who reported the following: (1) their degree of preference for a variety of generic engineering tasks (the Engineering Task Preference Questionnaire), (2) their degree of satisfaction with performance aspects of their ongoing projects (the Project Satisfaction Questionnaire), (3) the project phases when they communicate most intensively with their partners (the Communication Intensity Questionnaire).

The data from the Engineering Task Preference Questionnaire (N=192) was processed as follows. First, a statistical data-reduction technique [using the Statistical Package for the Social Sciences (SPSS)] was performed to identify underlying factors by which engineers vary from one another in the types of engineering work they value, prefer, or otherwise feel are important. Second, scores for those aggregate variables were computed and a Task Preference Profile was generated for each participant in the teams selected for examination in this study. A similar procedure was performed on the data from the Project Satisfaction Questionnaire (N=178) to produce a second profile, the Project Satisfaction Profile, for the individual application study participants. These engineer profiles, along with an item analysis of the original questionnaire scores for each team member, were helpful in building a comprehensive understanding of the distribution of attitudes and beliefs in the engineering teams observed in this study.

Data from the third questionnaire received a simple comparison-of-means analysis to identify the phases in a design project when team discourse was most intense, which, as it turns out, were the earliest phases. This study, therefore, targets the discourse from those project phases.

This section describes the participants, questionnaires, and procedures for collecting and analyzing the survey data.

Participants in Surveys

A sample of volunteers was drawn from a population of students in the Electrical and Computer Engineering Department at a large university in the U.S. Southwest. The students were enrolled in either of two courses, Electrical Engineering Projects Laboratory (referred to as Project Lab) and Engineering Communication (Engineering Comm). These two courses were selected for this study because they contained primarily junior- and senior-level engineering students and they both required that students complete long-term team projects. For the collection of task preference questionnaire data, the students from both courses were combined as a single population for analysis (N=192) to obtain as broad a depiction of junior and senior engineering students as possible. See Appendix B for a summary of the participants in this study.

In the Project Lab course (N=91), students form two-person teams, and each team is assigned to the task of solving an engineering design problem over the period of a semester. Each team works on a different problem. The students do not meet as a general body except during course orientation the first two weeks of the semester. After they divide into teams, they meet in various laboratories set up for the different problem areas: power, digital signal processing, audio/acoustics, telecommunications, control/robotics, and programming. A team may be working on their project while other teams are working on other projects in the same laboratory. Each team is under the supervision of a graduate teaching assistant (TA), who provides guidance, advice, and help with resources, but principally encourages the teams to explore on their own the alternative approaches to their problems. The department refers to the TA role as that of a coach or mentor.

The design problems are taken from real-world engineering situations, or they simulate such situations. In either case, the problems generally meet Goel and Pirolli's

(1991) definition of design problems in that they are ill-defined and semantically rich, and they require a range of engineering skills and knowledge. (See Chapter 1 and Appendix A for descriptions of engineering design from a cognitive theoretical perspective.) Like most engineering work, the projects must be documented: each project team prepares written and oral reports. Typical reports are a proposal, safety and ethics report, design review, progress report, and final report. In addition, the students must periodically give oral reports on aspects of their project. Though the writing component figures heavily in the course grade, the principal team requirement is to demonstrate technical competence.

In the Engineering Comm course (N=101) students meet in regular classrooms, but the student teams conduct their projects outside class during the last half of the semester. The project teams, which comprise two to four persons who select their own partners on the basis of similar interests, create scenarios in which the team members assume the roles of professional engineers. According to the scenarios, the management of a hypothetical firm has asked the engineering team to propose a new product or service to help the company improve its appeal to consumers or clients. On acceptance of their proposed idea (the instructor plays the role of management in these scenarios), the team conducts the necessary research to establish whether the proposed product or service is marketable and technically feasible. The project includes three collaborative writing assignments: a proposal, a progress report, and a final report, all addressed to "management." The principal factor governing the grade in this project is demonstration of communication skills.

Both courses involve students who are in their junior or senior years, and both courses give the students group problem-solving experience. The questionnaires, therefore, are useful for revealing underlying cognitive and communicative attitudes by which engineering students may be grouped. Those attitudinal factors, in turn, can be used to discern differences between members of the application study teams (who, after all, are sharing the same experience in the same course).

Questionnaires

As discussed in Chapter 2, a comprehensive understanding of collaborative problem-solving processes requires some knowledge of the problem solvers themselves and knowledge of the effects of the collaborative experience on the those solvers. To help identify appropriate parameters for comparing and contrasting the problem solvers in this study, two questionnaires are used: the Engineering Task Preferences Questionnaire (Appendix C) and the Project Satisfaction Questionnaire (Appendix D). In addition, a third questionnaire (the Communication Intensity Questionnaire) is used to identify when in a typical design project the communications between team members are most vigorous. The three questionnaires are described below.

The Engineering Task Preferences Questionnaire

The purpose of the Engineering Task Preferences Questionnaire (Appendix C) is to determine how students differ in the types of engineering tasks they personally prefer or think important. This information is used in this study to show how task- and project-related attitudes are distributed in each of the engineering teams. The questionnaire begins with the following instructions:

> As a professional engineer, you will have many ways to contribute to the operations of your company. Suppose you are beginning your job search now. What kind of job activities would you like to do for the firm that employs you? Place an "X" in the blank that most nearly expresses how important the activity is to you at the present time.

Following the instructions is a list of 24 common activities of professional engineers, and following each item is a Likert scale ranging from 1 (Not Important at All) to 4 (Extremely Important).

The questionnaire is slightly modified from one designed by McIlwee and Robinson for a study of professional women engineers and their perceived roles in the workplace (McIlwee & Robinson, 1992). Its value in this study lies in its comprehensive list of the types of engineering tasks that engineers normally encounter and its use in determining the participants' degree of interest in performing those tasks. The questionnaire was first administered to Project Lab students in the summer of 1999, and it showed adequate reliability (Cronbach's alpha >.80). The data of that pilot study was folded into the main study.

The questionnaire is used in this study because, upon examination, the listed items can be seen to vary in the degree they emphasize cognitive activity versus social and communicative activity. This variation suggests that participants who are more technically inclined may show a different scoring pattern than those who are more socially inclined. A factor analysis described later in this chapter is used to identify and label item groupings in which this differentiation becomes pronounced.

Note that McIlwee and Robinson designed the original questionnaire to determine attitudes of women engineers in their current jobs. The students in this study are predominantly male, and they have yet to enter their professional careers (although many have intern experience with large companies). This author believes, however, that the questionnaire (which is a listing of typical engineering tasks) is neutral in regard to gender. On the other hand, most students in this study have had scant or no professional experience. For that reason, the questionnaire can indicate only what the student engineers think they will like or dislike about their future professional lives. Those likes and dislikes are not based on actual experience. This use of the questionnaire for a population different from that for which the questionnaire was designed raises certain questions in validity and represent a limitation of this study.

The Project Satisfaction Questionnaire

The purpose of the Project Satisfaction Questionnaire (Appendix D) is to determine how students differ in their satisfaction with individual and team performance during their ongoing projects. As such, the questionnaire gives an important measure of project outcome, which can be used in the framework applications to compare team partners' assessments of their project experience. The questionnaire begins with the following instructions:

> Consider each of the following questions according to the totality of your experience in EE464 [or EE333T]. Please insert an "X" in the appropriate blank to indicate your level of agreement.

Following the instructions is a list of 35 statements, each addressing some aspect of project performance either of the individual or of the team as a whole. With each item is a Likert scale ranging from 1 (Strongly Disagree) to 4 (Strongly Agree).

The author of this study composed the questionnaire items to take into account four areas of participant satisfaction: the technical accomplishment of the team, the technical accomplishment of the individual, the quality of overall team communications, and the ability of the individual to communicate with a partner. Thus, as with the engineering preferences items, the items in this questionnaire target a range of activities from the primarily cognitive to the primarily social/communicative. Additional items were inserted to determine the degree to which participants felt they were able to assert their opinions, thought that their team communication improved over time, and took a global or local perspective on project activity. As described later in this chapter, a factor analysis was run on the questionnaire data to group items that collectively represent distinct variables.

The Communication Intensity Questionnaire

As described in numerous sources (for example, Pugh, 1991, and Goel & Pirolli, 1992), lengthy design projects proceed in phases reflecting the evolution of the design object. The purpose of the Communication Intensity Questionnaire was to determine which phases engender the greatest amount of interpersonal communications. (The working hypothesis is that the most intense discussions between team members generally occur during the initial phases of a project.) This study focuses on those phases to ensure the collection of a rich and varied sampling of project discourse. In addition, the questionnaire can provide insight into the communicative patterns of teams engaged in prolonged engineering design problem-solving. For instance, if participants reported that the quality of communication improved over the course of their project, the reason could be that their need to communicate became less urgent after the team members had agreed on definitions, goals, and a division of responsibilities. In addition, the information from this questionnaire is interesting for pedagogical reasons. For instance, if an instructor can know where in an engineering project effective team communication becomes critical or difficult, then that instructor can design classroom activities that focus on those areas.

The Communication Intensity Questionnaire is a list of eight project phases—from problem definition to final testing—and begins with the following instructions:

> Some project phases require more communication between you and your partner than others. Below are eight typical design phases. Enter in the blank beside each phase a number representing the intensity of your team's communication during that phase.
>
> Let 8 represent the most intense communication activity and 1 represent the least intense communication activity. Please give each phase a unique ranking, 1 though 8; that is, do not give two or more phases the same ranking.

The eight typical design project phases are as follows:

- Initial definition and clarification
- Analysis of problem specifications
- Design problem-solving

- Project planning and scheduling
- Research and computations
- Procurement of materials and components
- Implementation of design
- Testing, evaluation, and modification

This division is a composite of project breakouts from various sources in the literature of design and problem-solving (Ancona & Caldwell, 1990; Ball et al., 1994; Goel & Pirolli, 1992; Polya, 1957; Pugh, 1991).

Administration of Questionnaires

Efforts to obtain a representative data sample from junior and senior engineering students differed for the two courses. In Project Lab, respondents were recruited during course orientation at the beginning of the semester as follows:

1. All students were asked to consent to receiving a questionnaire (via e-mail) regarding their attitudes toward typical engineering activities (the Engineering Task Preference Questionnaire).

2. All students working in teams (thus excluding those few who worked alone) were asked to consent to receiving a questionnaire (via e-mail) regarding attitudes toward their current project activities (Project Satisfaction Question-

naire) and regarding communication levels during project phases (Communication Intensity Questionnaire).

Thus students in Project Lab who were working in teams and who had signed consent forms (Appendix E) received all three questionnaires and returned the questionnaires by e-mail during the latter quarter of the semester.

Students in Engineering Comm signed consent forms and completed the questionnaires by hand and in class at the conclusion of their projects near the end of the semester. The Engineering Comm students received only the Engineering Task Preference Questionnaire and the Project Satisfaction Questionnaire. The third, the Communication Intensity Questionnaire, was not considered applicable for the Engineering Comm projects; those projects were less typical of engineering design work and could not be broken down into the same phases as those for Engineering Lab projects.

Generation of Engineer Profiles

The purpose of the engineer profiles is to identify cognitive and social factors that differentiate members of the same application study team. Those factors are derived from statistical analyses of the item scores from the Engineering Task Preferences and the Project Satisfaction Questionnaires. The results are two engineer profiles: the Engineering Task Preference Profile and the Project Satisfaction Profile. The procedure for generating a profile is as follows:

1. Preliminary Analysis

   A preliminary analysis was conducted to determine whether the questionnaire responses represent those of a fair sampling of the population and demonstrates reliability. The means and variances of the data items were also examined for general sample trends and differences.

2. Factor Analysis

   The purpose of the factor analysis was to identify underlying variables (attitudes, beliefs, and assessments) that explain the pattern of responses on the questionnaire. A factor analysis reduces the amount of data from a questionnaire to a few factors, each representing the collective meaning of a number of questionnaire items that show a high degree of correlation. Thus, the factor analysis simplifies the process of discovering and identifying factors that may distinguish engineers from each other and that have particular relationships to design activity. In the factor analysis conducted in this study, the Statistical Package for the Social Sciences (SPSS) program was used (specifically, the Maximum Likelihood factor method, followed by a Promax, or oblique, rotation).

3. Identification of Factor Categories

   The SPSS factor analyses determined sets of questionnaire items with strong correlations. Items of each set were examined to identify a common underlying meaning or dominant idea, and the group of items was given a descriptive label. As a result, a small number of factor categories—more specifically, task-preference and project-satisfaction variables—were identified from the numerous questionnaire item results.

4. Generation of Profiles for Engineering Team Members

   For each factor category identified in the preceding step, scores were computed for each team member of the engineering team. For comparison purposes, the aggregate mean in each category were also computed for the entire population sample. Two tables—engineer profiles—were constructed for each participant, one showing the participant's mean scores for task-preference factor categories and the other showing the mean scores for project-satisfaction factor categories. The profiles for each member of a dyadic team were combined, along with the means of the population sample, into a single table for ease of comparison.

The resulting engineer profiles are used for each engineering team to generate hypotheses about and guide interpretation of the roles, cooperative forms, and group processes that appear in team discourse.

General questionnaire results and descriptions of the actual engineer profiles are given in Chapter 4. Interpretation of questionnaire results and profiles as they relate to actual engineering team data are given in Chapter 5.

COLLECTION OF INTERACTIONAL (PROCESS) DATA: THE APPLICATION STUDIES

The conditional and outcome factors derived from the questionnaire data and identified in the engineering profiles (see Table 3-1) were used to build a better understanding the application study team members. A third need for this study was insight into the team processes, that is, the members' interactional behaviors. This interactional data was assembled from interviews with the participants and analyses of the transcribed team dialogue. This combination of reported and observed perspectives was intended to provide a fuller knowledge of the team members as collaborating partners and the team as a problem-solving entity.

To provide interactional data, each of three two-person teams audiotaped their interpersonal conversations during the definitional and planning stages of their design project. Transcriptions of the tapes were examined, and selected interactions were coded for interactional focus; interactional roles; evidence of symmetry, alignment, and agreement; and cooperative forms, or patterns. In addition, the team members granted interviews in which they described the cognitive and communicative properties of their team.

This section describes the study participants, their work environments, the circumstances of the interviews with each participant, and the procedures for analyzing the team interactions.

Participants of Framework Application Studies

Only volunteers from the Project Lab course participated in the framework application studies. Engineering Comm students were not invited because the author (who was also the course instructor) could not expect natural conversation from teams who knew that their course instructor and project grader would be listening to their tape-recorded conversations. Moreover, the Engineering Comm projects consisted of various team sizes, which would complicate the analysis of their discourse beyond the scope of this study.

A background form and invitations to take part in the framework application studies (Appendix F) were extended to the Project Lab students during the general course orientation early in the semester. Teams who consented to audiotape their conversations were supplied audiotape audio-tape recorders and an ample supply of cassettes and batteries, and they received monetary compensation for their efforts as soon as they returned the tapes and equipment. A consent form (Appendix E) was used to obtain the team's permission to use the recorded data and their remarks during interviews.

Description of Team Environment

The participants in the application studies recorded their conversations while they carried out their work in laboratories. These laboratories were designed specifically for engineering projects and experiments. Instrumentation, tools, materials, and computers with the necessary software were either already installed in the laboratory or could be checked out from a nearby parts bin. Vendor manuals and catalogues were available, and the teams had access to faculty members to discuss concepts. Generally more than one team was working on a project in the laboratory at any given time, and sometimes the teams interacted on matters of course procedures. Each team was under the supervision of a graduate TA, who provided advice and help with resources but seldom gave direct solutions to specific problems. The intent of the TAs and the course itself was to encourage the teams to explore alternative solutions and examine the various tradeoffs. Thus, the teams had considerable autonomy in the way they planned and conducted their projects.

Data-Gathering Procedures

Two methods were used to gain insights into the problem-solving characteristics of each team in the three application studies: tape-recordings of actual discourse and personal interviews with the individual team members. Each of these methods, along with the criteria for selecting teams for the framework application study, is described below.

Obtaining Discourse Protocols

The team members themselves recorded their discourse by carrying an audio-tape recorder about their persons as they worked together and conducted face-to-face discussions in the laboratory. At no time was the researcher present during the recorded sessions: the intent was to capture natural, free-flowing conversation between peers and to minimize any distraction that may interfere with the students' ability to do well in their project. The recording period began soon after the teams learned the nature of their design problems and ended when the teams began to prepare their written proposals (a period of two to three weeks), since presumably by that time the team members had defined their problem and agreed to a preliminary plan or approach to a design solution. This period of the project was selected because the early results from the Communication Intensity Questionnaire indicated that collaborative activity was most vigorous during the early definitional and planning phases of design projects. On average, the teams provided six to seven hours of recorded conversation, with fifteen hours at the most. Because of the academic importance of the course to the participants and because of the considerable inconvenience of tape recording work sessions over many days, the author offered the participants monetary inducements to take part in the study.

Conducting Interviews

Near the end of the semester, the researcher interviewed team members individually. The objective of these open-ended interviews was to gain insight into the projects from the participants' point of view. The participants were invited to speak openly and informally of their project experience. They spoke of what went well, what went right, what they might have improved, where they disagreed with their partner, how they divided the task and why they divided it that way, how the team members got along, and so on. By revealing their attitudes and talking about their lessons learned, the participants provided the researcher with additional information for interpreting the problem-solving interactions recorded in the protocols. The interviews took place in the researcher's office and were recorded on audiotape. (Not all the participants submitted to the interview.) Immediately after each interview, the researcher reviewed the recording, took notes of the significant ideas, and checked his interpretation with the participant by phone. The participant was invited to add, modify, or retract any information he or she had given.

Selecting Framework-Application Study Teams

Over a three-semester period, a total of eighteen teams volunteered for the application study (see Appendix B), and of those teams, three teams were selected. To be selected, a team had to meet three criteria. First, the quality of their recordings had to meet a minimum standard of clarity. Second, only those teams were considered in which both members filled out the Engineering Task Preferences Questionnaire and the Project Performance Questionnaire. Data from these questionnaires was necessary to build engineer profiles. Third, both members of the team were required to grant an interview at the end of their projects.

Out of the eighteen teams, only eight met all three criteria. Transcripts from those eight teams were examined for the following subjective considerations: apparent maturity of students, range of interactions (in some tapes, one speaker did essentially *all* the talking with the other speaker providing a steady stream of backchanneling), depth of engagement with the design problem, and a minimum amount of off-task dialogue.

Finally, to identify the three dyads for the application studies, the author reviewed the engineer profiles (described in Chapter 4), especially the Project Satisfaction Profiles, and compared the partners' levels of satisfaction with the cognitive and communicative aspects of their projects. By selecting teams whose partners contrasted in different ways, the author hoped to observe a range of collaborative styles and cooperative forms in team dialogues. As a result, the teams chosen had the following characteristics:

Application Study Team 1: Both partners report strong satisfaction with team communications and team technical accomplishment. Partners differ in their satisfaction with personal technical performance (mild dissatisfaction versus extreme satisfaction).

Application Study Team 2: Both partners report strong satisfaction with team communications and mild versus strong satisfaction with team technical accomplishment. Partners report mild versus strong dissatisfaction with personal technical performance.

Application Study Team 3: Partners differ in all three areas: team communications (strong satisfaction versus strong dissatisfaction), team technical accomplishment (mild satisfaction versus extreme dissatisfaction), and personal technical performance (neutral to extreme satisfaction).

Thus, in the final selection of teams for the application studies, the primary consideration was to test the ability of the framework to describe or identify cooperative forms within teams representing a range of cognitive and communicative properties, as revealed by the Project Satisfaction Profiles. No consideration was given to other defining properties, such as team composition in gender, language proficiency, age differences, and so on. As discussed in Chapter 2, those individual differences are important in determining the types of cooperative forms that may appear in a team's discourse; however, the purpose of this study is to devise a system for identifying and describing the cooperative forms of productive interactions, not to explore the underlying psychological and social causes of their appearances.

Procedures

The interactional analysis (see Table 3-1) for each application study team encompasses a member-comparison analysis (based on the conditional and outcome variables derived from questionnaires and profile data) and a process analysis based on the transcriptions of team problem-solving conversations and interviews. The use of the questionnaire data has been described in previous sections. This section describes the procedures for analyzing team interactions (see under "Process" in Table 3-1).

The recordings from the application study teams were transcribed primarily by the author, but with considerable assistance from a professional transcription service. Tapes from all 18 teams were transcribed because, though some teams obviously failed to meet the inclusion criteria of the study, their dialogue nevertheless was thought valuable for future research. The transcriptions were generally completed well after the projects were over and in many cases after the participants had graduated. The participants, in other words, were not available to read and correct the voluminous transcriptions. For that reason, the author formed a Technical Advisory Team of five graduate engineers whose responsibility was to examine the protocol data for accuracy of transcription and interpretation. In addition, the Advisory Team gave the author help in understanding and describing the technical terms and procedures that arose in the application study teams' operations.

The transcriptions were examined and encoded according to the following steps (see "Process" portion of Table 3-1):

1. *Determining Interactional Boundaries.* The transcription were divided into interactional sequences.

An interactional sequence is defined by Hogan et al. as a unit of dialogue that begins when a speaker makes a conceptual or metacognitive statement or poses a question or query that signals a new topic for discussion (Hogan et al., 2000). The sequence continues through at least one response from another speaker or a string of turns from both speakers. The interaction sequence ends when a speaker "steps back from the flow of the interaction by posing a new question or query; by making a metacomment that regulates, focuses, or evaluates the action; or by introducing a conceptual statement that refocuses the discussion" (Hogan et al., 2000, p. 390).

The current study supplements this definition for the ideal case: A complete and well-developed interaction sequence in purposeful discourse begins when an initiator opens a topic and controlling idea with a statement, question, or a query, continues through a body in which the interlocutors reciprocally clarify, modify, or augment their mutual understanding of the topic, and a conclusion when the interlocutors agree or accept that no more can be said productively at that time or they otherwise give signs that the interaction is over (Hinde, 1979). Many interactions are quite short, but some may extend over several minutes and comprise many turns. Some interactions seem nested in larger discussions or contributory to an ongoing flow of thought, whereas others seem to be entirely random engagements.

2. *Encoding Interactional Focus.* Each interactional sequence by definition has a semantic focus. The focus of each interactional sequence was categorized and coded as one of the following: Project Goal, Project Mediation, Project Team, and Off-Task (Table 3-2). These categories are quite similar to those in Hogan et al. (2000), but they have been expanded and redefined somewhat for application specifically to design projects.

TABLE 3-2
DEFINITIONS OF INTERACTIONAL FOCUS CATEGORIES

Name	Definition
Project Goal	Focus is on the product or process representing the project goal state or any of its details. Includes subgoals, events, and milestones marking progress along the critical path.
Project Mediation	Focus is on the logistics, tools, procedures, resources, standards, and constraints that mediate the team's operations.
Project Team	Focus is on the team as a problem-solving unit and on its distribution of skills and knowledge in relation to the problem.
Off-Task	Focus apparently has nothing to do with the project.

A *Project Goal* focus is any topic relating to the project goal state or any of its details. It includes all exchanges that pertain to activities on the critical path to the design solution and which are intended to screen an idea for entry into the team's common ground of knowledge about the problem solution (see Clark

& Brennan, 1991). Group processes within task topics usually have to do with reaching mutual understandings and agreements about the problem solution.

A *Project Mediation* focus is any topic related to the team's efforts to position itself efficaciously to solving or understanding the problem or task. Hogan (2000) identifies several types of metacognitive statements, but here the category is somewhat redefined to characterize topic areas in which discussion is intended to enhance the problem-solving capacity of the team in some way. The topic sub-areas are as follows: (1) subtopics regarding *internal team regulation*; that is, team-decided issues regarding the direction of team activities, problem-solving plans and procedures, division of labor, or local matters of logistics; (2) subtopics regarding the *evaluation* of team progress; and (3) subtopics regarding *external criteria, constraints, or standards* controlling the group's process, product, or operation. (see Hogan et al., 2000, p. 389).

A *Project Team* focus is any topic related to any overt attempt of the partners to build a mutual knowledge of their individual and combined knowledge, skills, and other resources. The topic includes disclosures of and inquiries about what the partners may or may not know about their own or their partner's capacity to perform the work, attitudes toward the work, expectations about the other's response to information, and so on. This process of building a common ground during a long-term project requires not only that one member knows what the other member knows, but also that the other member knows that he or she knows (Clark & Brennan, 1991).

An *Offtask* topic is any topic that cannot be related to the problem-solving effort. Such topics often are humorous comments to relieve tension.

3. *Encoding Interactional Roles.* For each interaction, significant utterances are coded according to the roles the participants are performing by uttering them. These roles are tabulated for each partner and then compared.

   Roles are Proposer, Critiquer, Reporter, Responder, Explainer, Monitor-Standards, and many others (Table 3-3). These roles, in turn, are categorized as Conceptual, Team Regulation, Interactional Alignment, and Other. A few of the roles (Proposer, Implementer, Evaluator) were suggested in studies such as Hogan (2000) and Baker (2002). Because the design problem-solving interactions examined in this study are more complex and multilayered than those in many earlier studies, the author of this study, after numerous passes through the transcriptions, has identified and defined many additional roles, such as Monitor-Alignment, Explicitator-Partner, and Explicitator-Self..

TABLE 3-3 INTERACTIONAL ROLES DEFINITIONS AND CODES

Category	Role	Definition	Code
Conceptual	Proposer	Proposes an action or idea; proposes a solution of a problem or sub-problem.	Prop
	Elaborator-Self	Expands and/or deepens one's own idea, decision, or proposal. Gives reasoning process for idea. (If idea is contested, see Justifier below.)	El-S
	Elaborator-Partner	Expands and/or deepens partner's idea, decision, or proposal. Supports reasoning. (If contesting the idea, see Critiquer below).	El-P
	Justifier	Like Elaborator-Self, but aim is to justify an idea that is contested or questioned.	Just
	Critiquer	Contests or questions the partner's idea.	Crit
	Explainer	Explains procedures, actions, physical processes, features/ functions of objects, etc. Aim is to provide information for general team needs.	Expla
	Analyst	Identifies/describes subproblems, discrepancies, inconsistencies, etc. Breaks down processes into steps. Usually *precedes* a proposal or decision.	Anal
	Presenter	Presents, names, and describes items in view. Topic can be pointed at.	Pres
	Reporter	Reports/describes previous or ongoing action or decision. Debriefs partner.	Rprt
	Partial-Informant	Starts an idea but fails to complete it.	PI
Team Regulation	Monitor-Standards	Relates to external standards, rules, procedures, instructions, etc.	Mon-S
	Regulator	Directs or regulates joint or individual action and decision-making. Directs action on a general task. Monitors conformance with past team (internal) actions and decisions.	Reg
	Implementer	Relates to actions or procedures to implement a specific decision or proposed solution (as opposed to a general task)..	Impl
	Specifier	Specifies a team need (material or informational) or the properties and characteristics of items (tool, component, material, etc.) for procurement.	Spec
	Evaluator-Resource	Evaluates data, component, instrument, catalog, etc. (or their sources).	Ev-R
	Evaluator-Self	Evaluates one's own ideas, work, experience, understanding, ability, decision making, or communications.	Ev-S
	Evaluator-Partner	Evaluates partner's ideas, work, experience, understanding, abilities, decision making, or communications.	Ev-P
	Evaluator-Team	Evaluates team ideas, work, experience, understanding, ability, decision making, or communications.	Ev-Te
	Evaluator-Task	Evaluates the task difficulty or problem solvability.	Ev-Ta
	Evaluator-Results	Evaluates the results of an action or decision.	Ev-R

TABLE 3-3–INTERACTIONAL ROLES (Cont)
DEFINITIONS AND CODES

Category	Role	Definition	Code
Interac-tional Alignment	Monitor-Align	Relates to mutual understanding and alignment in thinking. Verifies understanding or indicates lack of understanding.	Mon-A
	Explicitator-Self	Makes one's own idea more explicit or emphatic, or states inferences from that idea to ensure mutual understanding in the immediate context of thinking. Makes explicit exactly what one is or is not talking or thinking about to ensure alignment or to differentiate from opposing idea.	Expli-S
	Explicitator-Part	Same as above but relates to the partner's idea.	Expli-P
	Summarizer	Repeats old information (common ground) to ensure mutual understanding.	Sum
	Repeater-Self	Repeats one's own words.	Rpet-S
	Repeater-Partner	Repeats the partner's words.	Rpet-P
	Opener	Identifies the topic of the upcoming interaction or turn sequence.	Open
	Querier	Raises a topic for consideration.	Q
	Requestor-Info	Requests information.	Req-I
	Requestor-Opinion	Requests an simple opinion or choice from alternatives.	Req-O
	Requestor-Clarify	Requests that the partner clarify a statement or idea.	Req-Cl
	Requestor-Confirm	Requests for a sign of confirmation, agreement, or understanding.	Req-Cf
	Responder-Agrees	Responds positively to the partner.	Res+
	Responder-Neutral	Responds noncommittally to partner. Usually a continuer.	Res
	Responder-Disagr	Responds negatively to the partner.	Res-
	Responder-Opinion	Responds with an simple opinion or choice of alternatives.	Res-O
Other	Uncod-able/Unclear	None of the above, or indecipherable.	Unc
	Digression	No apparent relationship to task, project, or team.	Dig

4. *Encoding Cooperative Forms.* The roles are tabulated and examined for team symmetry, alignment, and agreement/acceptance. Combinations of these elements define the cooperative form of the interaction (Table 3-4).

The terms *symmetry*, *alignment*, and *agreement* are those of Baker (2002) and are defined in Chapter 2. The purpose of this step is to characterize the

TABLE 3-4
DEFINITIONS OF COOPERATIVE FORMS [a]

Cooperative Form	Definition
Co-construction	Interaction is symmetrical and aligned. Partners are in agreement. Both build on each other's ideas reciprocally and progressively.
Apparent co-construction	Interaction is symmetrical, but unaligned, and partners are in agreement. Partners' proposals are non sequiturs. Partners do not share the same sense of each other's contributions, though they may be stimulated by what they think they understand. They may be working in parallel.
Co-argumentation	Interaction is symmetrical and aligned, but partners disagree. Usually indicated by a proposal followed by a counterproposal of equal substance. Marked by justification and elaboration as both partners defend their positions.
Apparent co-argumentation	Interaction is symmetrical and unaligned. Partners disagree. "Arguing past each other."
Acquiescent co-elaboration	Interaction is asymmetrical and aligned. Partners are in agreement. One partner generates ideas while the other gives feedback, responds with an opinion, shows agreement, or encourages the speaker to continue. Hogan et al. (2000) refer to this pattern as consensual.
Apparent acquiescent co-elaboration	Interaction is asymmetrical and unaligned. Partners appear to agree, but there is a lack of mutual understanding. Feedback is off the mark or contradicts speaker, speaker does not respond appropriately to feedback, or speaker ignores feedback.
One-sided argumentation	Interaction is asymmetrical and aligned. Partners explicitly disagree, but only one partner is generating ideas.
Apparent one-sided argumentation	Interaction is asymmetrical and unaligned. One partner is generating ideas, and the other partner disagrees without understanding those ideas.

[a] See (Baker, 2002)

problem-solving interactions in terms of cooperative forms. For example, at critical decision points, how frequently do the partners co-construct knowledge, or does one propose a solution while the other acquiesces, or do they both argue different points of view? These different ways of relating simultaneously to each other and to the problem depend on the degree of symmetry, alignment, and agreement that prevails between the two partners' contributions.

5. *Perform Interpretive Study.* The final step is to interpret the relationships among cooperative forms and roles, task-preference data, project-satisfaction data, and interview data to develop a comprehensive understanding of the unique properties of the team. As much as possible, this discussion will link the cooperative forms to the group learning processes/mechanisms described in Chapter 2.

Thus the overall design of the study incorporates considerations of the properties of the participants, the interactional processes, and the attitudinal outcomes of the interactions/project. This tripartite view is intended to give a comprehensive depiction of the application study team as a distinct problem-solving unit.

CREDIBILITY AND RELIABILITY

Because only the researcher was immersed in the application study data, efforts were made to preserve trustworthiness partly by the design of the study and partly by the checks provided by the Technical Advisory Team of five graduate engineering students. First, the engineer profiles, especially the project-satisfaction profile, provide a basis for building working hypotheses about the general quality of a given team's interactions. The analysis of the actual protocol data, therefore, is a continuous process of refining those hypotheses (negative case analysis) as well as discovering relationships that are unexpected (Lincoln & Guba, 1985). Second, during interviews with the team members, the researcher was able to confirm or correct initial hypotheses of team interactions. Third, the Advisory Team actively reviewed and critiqued the researcher's coding system, the identification of topic categories, the coding of interactional roles and cooperative forms, and general interpretations of what the teams were doing in critical passages of the protocols.

CONCLUSION

This chapter has described the design of this study as depicted in Figure 3-1. The population is junior and senior engineering students engaged in long-term projects. Two instruments—an Engineering Task Preference Questionnaire and a Project Satisfaction Questionnaire—are administered to a sample of this population to determine attitudes toward types of engineering tasks and levels of satisfaction with individual and team project performance. A data-reduction routine, or factor analysis, is applied to the data to consolidate groups of related questionnaire items into a few aggregate factors, each of which target a single underlying meaning. Scores for those factors are then computed for each member of the application study teams. The resulting engineer profiles for team members are compared, and hypotheses are generated regarding the manner that the team members can be expected to collaborate.

To confirm or modify the hypotheses drawn from the profile comparisons, team interactions selected from the protocols are examined for patterns in collaborative interactions, the distribution of interactional roles, and the cooperative form(s) that characterize the team's interactions. Finally, those forms are interpreted in light of the profile and interview data to obtain a description of the team's unique properties. This interpretive procedure focuses on how the team members manage their differences (and similarities) to become a single coherent cognitive system.

The general results of the questionnaires and the generation of the engineer profiles from those results are described in Chapter 4, and the application studies are presented in Chapter 5.

CHAPTER 4
RESULTS FROM QUESTIONNAIRES AND THE GENERATION OF PROFILES

This chapter presents the scores of the Engineering Task Preferences Questionnaire and the Project Satisfaction Questionnaire and describes the statistical analyses of the questionnaire results to identify aggregate factors, that is, groups of items that share underlying meanings. Those item groups become the bases of engineer profiles for the participants in the application studies. The profiles, in turn, are used in the application studies to give insights into the interactions between team members in Chapter 5. Finally, the chapter gives the results of the Communication Intensity Questionnaire, which supports the hypothesis that intra-team communication is most intense during the definitional and planning stages of long-term ill-defined collaborative problem solving projects.

RESULTS FROM THE ENGINEERING TASK PREFERENCES QUESTIONNAIRE

The purpose of the Engineering Task Preferences Questionnaire is to capture the degree of importance that different student engineers attach to the range of common engineering tasks and activities. The results of the questionnaire are tabulated in Appendix G for the population sample and for each participant in the application studies. For a measure the reliability of the instrument, SPSS was used to find the proportion of variability in the responses to the questionnaire that is the result of the differences in the respondents. The test chosen was Cronbach's alpha reliability, which yielded an alpha greater than .84, that is, the lower bound for the true reliability. Item means for the population sample range from 3.72 (*Q2-To work on projects that interest me technically*) to

2.08 (*Q18-To present papers at professional societies*). A review of the mean sample scores reveals that, as mean scores increase, the standard deviations decrease. The Pearson's coefficient for the correlation between means and standard deviation is r = -.86, which is significant at the .01 level. An interpretation is that student engineers are fairly unanimous when judging the tasks they see as immediately important to them, but they become less so when considering tasks they deem farther in their futures.

An SPSS data-reduction routine using the Maximum Likelihood extraction method with Promax oblique rotation was applied to the questionnaire scores, and eight factors, that is, groups of variables that showed strong interrelationships and that can be labeled according to their shared meaning. Those labels thus become a few parsimonious descriptors for grouping of items taken from the entire set of items. Together, the factors account for 69 percent of the total variance. Repeated runs of the data-reduction routine and analyses of the scree plot and pattern matrix of each run (Appendix H), however, indicated only three stable, unambiguous factors. The Maximum Likelihood method was rerun with the number of factors set at three and the loading coefficient reset to show only those items with loading factors over .30. The resulting three factors accounted for 44 percent of the total variance. Table 4-1 on the next page shows the three factor categories, their labels, and their questionnaire items.

A close examination of the questionnaire items in the first factor category indicates that all have general management or corporate-level themes. For that reason, the group is labeled Management-Corporate. This category seems to encompass activities that are more communicative and social in nature. In contrast, the items in the second

TABLE 4-1
ENGINEERING TASK PREFERENCE QUESTIONNAIRE FACTOR CATEGORIES

Factor Category (Label)	Questionnaire Item
Management-Corporate (MGMTCORP)	Q21 To have the respect of my colleagues on my managerial ability. Q13 To learn how the business is set up and run. Q14 To earn the respect of my colleagues on my managerial abilities. Q11 To manage the work of others. Q4 To contribute to the business needs of the company. Q12 To prepare and deliver oral presentations to upper management. Q2 To work on projects that have a direct impact on the business success of the company. Q22 To have the required command of English to present myself and my ideas well. Q24 To eventually start my own business. Q1 To help my company build its reputation as a first-class organization. Q9 To work under capable management.
Microtechnical (MICROT)	Q6 To explore new and innovative technologies. Q10 To work on projects that incorporate advanced theories in my field. Q5 To work on projects that I have originated. Q3 To work on projects that interest me technically. Q8 To work with others who are outstanding in their technical achievement. Q7 To learn my job well and be able to stick to what I know.
Higher Professional (HIPRO)	Q17 To publish articles in technical journals. Q18 To present papers at professional societies. Q16 To receive patents on my technical ideas. Q20 To have the respect of my colleagues on my technical abilities. Q15 To become well-known outside my company as an authority in my field. Q19 To be evaluated only on my technical competency.

factor category have themes related to the technical or computational work of engineers.This factor category is labeled Microtechnical, and its activities are more cognitive and individualistic in nature. At first, the third category seems to have two interpretations. On one hand, the items listed represent activities expected of a career-oriented engineer. On the other hand, they all raise issues of professional respect and recognition. In fact, these two interpretations are regarded as one—valorization of one's membership in the larger community of engineers—and the category is labeled Higher Professional.

To construct the engineer profile for each participant in the application studies, the mean of the item scores in each factor categories was calculated for each participant and entered into a table. That table represents the Engineering Task Preferences Profile for the given participant. In addition, the overall profile for the population was calculated and entered into the table for comparison purposes. Examples of the profiles for two members of a hypothetical team are given in Table 4-2.

As shown, the profile for each team member is a row on the table giving the mean score for each aggregate factor. In Chapter 5, Three Applications of the Interactional

TABLE 4-2
EXAMPLES OF ENGINEER TASK PREFERENCES PROFILES

<table>
<tr><th colspan="2" rowspan="2">Profiles</th><th colspan="3">Engineering Task Preferences (a)</th></tr>
<tr><th>Management-Corp</th><th>Microtechnical</th><th>Higher Profes-sional</th></tr>
<tr><td colspan="2">Profile of Over-all Sample</td><td>M=3.04</td><td>M=3.15</td><td>M=2.52</td></tr>
<tr><td rowspan="2">Team X</td><td>Profile of Partner A</td><td>2.64</td><td>2.00</td><td>1.83</td></tr>
<tr><td>Profile of Partner B</td><td>3.36</td><td>2.50</td><td>1.83</td></tr>
</table>

(a) Values range from 1 (Not Important at All) to 4 (Extremely Important).

Framework, the profiles of application study team members are compared to determine in what respects the team members differ (or are the same). Those differences may help explain some the interactional behaviors appearing in the team's dialogue.

RESULTS FROM THE PROJECT SATISFACTION QUESTIONNAIRE

The purpose of the Project Satisfaction Questionnaire is to capture the participants' responses toward the collaborative aspects of a recently completed engineering design project. The results of the questionnaire are tabulated in Appendix I for the population sample and for each participant in the application studies. Again, the questionnaire reliability was fairly high (Cronbach's alpha of .76).

As with the previous questionnaire, the SPSS data-reduction routine (specifically, a factor analysis using the Maximum-Likelihood extraction method with Promax rotation) was applied to the 35-item questionnaire results to extract and consolidate variables into a relatively few aggregate factors. The scree plot from the first trial run of the factor analysis suggested that approximately seven to eight factors were particularly meaningful. In addition, an examination of the first rotated factor pattern matrix revealed that several items in given groupings showed only poor or ambiguous correspondence in meaning to other items in the groupings. To effectively eliminate those items, the displayed loading factor was increased from .30 to .35, and the factor analysis was rerun for eight factors. The scree plot and the final pattern matrix are shown in Appendix J. The result was eight factor categories (Table 4-3), each representing a participant's satisfaction with or attitude toward some aspect of the collaborative project experience.

TABLE 4-3
PROJECT SATISFACTION FACTOR CATEGORIES

Factor Category Label	Questionnaire Items
Satisfaction with Team Communication Efficiency (TeamComm)	Q27 Most of the time, my lab partner and I have difficulty communicating Q34 Sometimes my partner and I give up trying to understand each other on a point and just go to another topic. Q12 I am often confused by my partner's spoken English. Q28 There are times when I only pretend to understand what my lab partner is saying. Q10 When I disagree with my partner on a technical issue, I sometimes go along with his or her opinion because I'm afraid I can't express my own opinion convincingly. Q31 Overall, I feel that my lab partner and I communicate smoothly and effectively. Q30 I feel that at times my partner is confused by my spoken English. Q35 I sometimes know a better way to get a task done, but I'm unable to communicate my idea to my partner. Q5 Because of communication difficulties with my partner, I feel I sometimes have to compromise on what I think is the best technical course of action for our project. Q20 My partner and I seldom engage in social discourse.
Satisfaction with Individual Technical Ability (IndTech)	Q9 I feel that I have the technical competence to do the work in our project. Q16 I sometimes feel that my technical knowledge is inadequate for the project I've been assigned. Q21 I usually let my lab partner speak for our project during discussions with our teaching assistant or adviser. Q26 I tend to set the general direction and goals of our task and rely on my partner to supply the technical details.
Satisfaction with Team Accomplishment (TeamTech)	Q3 I feel I could have worked more effectively alone. Q17 I feel that my partner and I accomplish more as a team than either of us could accomplish alone. Q19 I feel that the quality of our work has depended largely on the ability of my partner and me to communicate well. Q32 Frequently, when we discuss the project with our TA, I find that I do most of the talking.
Awareness of Engineering Communication Style (CommAwr)	Q2 During our discussions, my partner and I often have to clarify an idea by drawing a sketch or diagram. Q1 I'm self-conscious about my speaking ability when my partner and I discuss engineering topics. Q6 I usually communicate better (in English) with my fellow engineers than with my non-engineering friends and acquaintances. Q15 When we're meeting with our TA, I make a special effort to "talk like an engineer."

TABLE 4-3 (Cont)
PROJECT SATISFACTION CATEGORIES

Factor Category Label	Questionnaire Items
Communication Assistance (CommAsst)	Q13 During our work, I frequently help my lab partner phrase his or her thoughts in clear English. Q24 During our work together, I frequently help my lab partner put into words something he or she is attempting to express.
Communication Improvement (CommImpr)	Q8 Generally, as the project continues, I find that my partner and I are gradually adjusting to each other's communication style. Q4 The longer we work together, the better my partner and I are able to communicate. Q7 My ability to express myself generally improves when my partner and I converse on a social level.
Communication Confidence (CommConf)	Q25 I speak much more fluently and freely when the TA is not present. Q33 I have confidence in my abilities to communicate as an engineer.
Satisfaction with Participation Level (Part)	Q29 I feel I have been able to participate fully in my team's decision-making.

Labels were assigned to the factor categories to capture the collective sense of the included items, as follows:

- Satisfaction with Team Communication (TeamComm): Items relating to the participant's satisfaction with the quality of communication between team members.

- Satisfaction with Individual Technical Ability (IndTech): Items relating to the participant's assessment of his or her own technical competence.

- Satisfaction with the Team Accomplishment (TeamTech): Items relating to the participant's satisfaction with the team's overall technical achievement.

- Awareness of Engineering Communication Style (CommAwr): Items relating to the participant's awareness of communicative issues or the role of communication in project success. This is the most problematical of the eight factors.

- Communication assistance (CommAsst): Items relating to the participants' willingness to help partners express their thoughts or the degree that the participant received such help.

- Perception of Communication Improvement (CommImpr): Items relating to the participant's sense that the communication between team members improved over the course of the project.

- Communication Confidence (CommConf): Items relating to the participant's willingness to initiate communication in different team situations.

- Satisfaction with Participation Level (Part): A single item relating to the participants sense of full participation in the project.

Note that, where applicable, any score (Likert scores 1 and 2) indicating disagreement with a statement that itself expresses dissatisfaction with an aspect of team experience was reversed (to Likert scores 4 and 3 respectively) to show agreement with a positive statement of the same idea.

While Satisfaction with Team Communication, Satisfaction with Individual Technical Ability, Satisfaction with Team Accomplishment, and Communication Improvement were anticipated, the remaining four factor categories were not. Of those four, Communication Assistance, Communication Confidence, and Satisfaction with Participation Level represent plausible groupings; however, the common thematic thread is less obvious in Awareness of Engineering Communication Style. That factor category is given that label because each of the items relates somewhat to an awareness of engineering modes and styles of communication. This last factor perhaps can be associated with the respondent's satisfaction with his or her ability to sound and act "like an engineer." As Lave and Wenger (1991) have argued, the acting out of different roles and the adopting of different ways of speaking are preparatory to becoming a contributing member of a community of practice.

The Project Satisfaction Profile for each participant in the application studies consists of the mean of the individual's scores for all items in a given category. Table 4-4 shows the Project Satisfaction Profiles for two partners of a typical project team.

TABLE 4-4
EXAMPLES OF PROJECT SATISFACTION PROFILES

Profiles		Project Satisfaction Categories (a)							
		Team Comm.	Ind. Tech.	Team Tech	Comm. Aware.	Comm. Asst.	Comm. Impr.	Comm. Conf	Part Lev
Profile of Overall Sample		*3.27*	*3.03*	*3.04*	*2.32*	*2.13*	*3.19*	*3.13*	*3.60*
Team Y	Profile of Partner A	3.33	2.20	2.67	2.20	1.00	3.00	4.00	3.00
	Profile of Partner B	3.44	2.20	3.33	2.80	1.00	3.33	3.50	4.00

(a) Values range from 1 (Strong Negative Response to Factor Category Items) to 4 (Strong Positive Response).

SUMMARY OF ENGINEER PROFILES

Appendix K is a table combining both types of engineer profiles (Task Preferences and Project Satisfaction) for all six members of the three application study teams. In addition, in Chapter 5 the profiles for each team are reproduced to compare and contrast the task preferences and project attitudes of the team members and gain insights into the conditions for and outcomes of team interactions. The analysis of the profiles—combined with item-by-item analyses of the questionnaire results, an examination of the interviews with the participants, and of course the analysis of certain application study interactions—should yield a better understanding of engineering problem-solving collaboration. In the third application study in Chapter 5, an attempt will be made to interpret the team's collaborative behaviors from information derived from the profiles and interactions alone.

RESULTS FROM THE COMMUNICATION INTENSITY QUESTIONNAIRE

The purpose of the Communication Intensity Questionnaire is to explore the hypothesis that communication between partners at work on an ill-defined problem is most vigorous during the early phases of the project, that is, the problem-definition and project-planning stages. As described in Chapter 3, the respondents (restricted to Project Lab students; N=69) were given a list of typical project phases and activities and were asked to rank them (1 though 8) from the most communicatively intense (a ranking of 8) to the least (a ranking of 1). The study computed the mean rankings for each of the eight project phases. The results, shown in Figure 4-1, indicate that participants tended to agree that communication between partners is most intense during sessions when they initially define the problem, analyze the problem specifications, and engage in problem-solving. The next tier of communicative activity is during planning, design implementation, and testing. Communication intensity is least during research and procurement. This information supports the decision to limit the scope of this study to the earliest stages of the participants' projects, when interaction and group processes are most robust.

CONCLUSION

This chapter has presented the data from the Engineering Task Preference Questionnaire and the Project Satisfaction Questionnaire. Based on factor analyses of

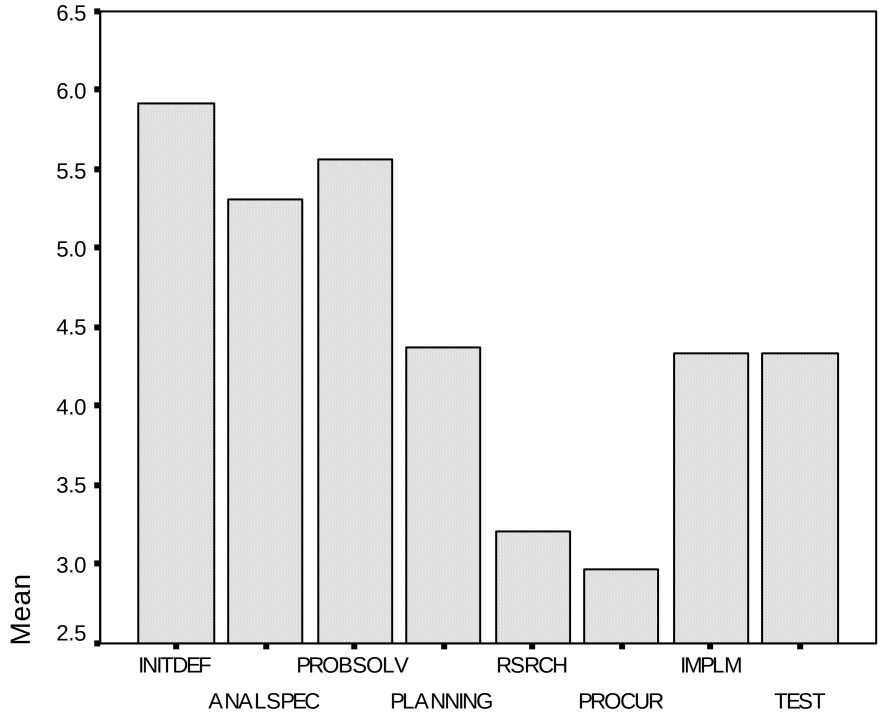


Figure 4-1 Communication Intensity During Eight Design Project Phases

those sets of data, two types of engineer profiles are generated for each participant in the application studies described in the next chapter. One profile shows the degree that the participant prefers or values tasks in management-corporation, microtechnical, and high-professional activities. The other profile shows the degree that the individual responds positively toward specific aspects of team and individual performance during an extended project. Appendix K shows the engineer profiles for all application study participants arranged according to teams. A comparison of the profiles is a preliminary step to understanding the conditions and outcomes of team interactions and thus additional perspectives on the collaborative processes discovered in the application study protocols.

CHAPTER 5
THREE APPLICATIONS OF THE INTERACTIONAL FRAMEWORK

A goal of the application studies is to identify possible relationships—within a given design team—between the task preferences of team partners and the cooperative forms they use in dialogue and between the cooperative forms and partner attitudes toward their team and individual performance. Three application studies were conducted to investigate those relationships as they emerge from interview data, questionnaire and profile results, and typical team interactions. The participants in this investigation are two-member teams of engineers attempting to define and plan a project to solve a complex design problem over a period of two or more weeks.

The purpose of this chapter is twofold: (1) to assess the relationship of certain differences in the communicative and cognitive makeup of team memberships to the cooperative forms the teams adopt, and (2) to test the efficacy of the descriptive framework used in this study to reveal those relationships. Practical circumstances in research and work environments may prevent the full use of the framework as depicted and described in Chapter 3. For example, interviews with many participants may not be possible. Moreover, the engineer profiles consolidate information from the questionnaires, and consideration of both sources of data seems redundant. Therefore, the simplest and most parsimonious use of the descriptive framework may rest on only three of its features: the two engineer profiles and the interactional data itself. Granted, the more a researcher knows about a study's participants the better the interpretive results are likely to be; however, a test of the framework developed in this study may be to determine how informative and descriptive it might be when its use is limited to its essential parts.

For those reasons, the three application studies in this chapter differ in the extent they employ the features of the framework. application study 1 makes full use of the framework (including extensive excerpts from the interviews and detailed item analyses from the questionnaires). Application Study 2 makes less use of the interview data, and the questionnaire item analysis is somewhat abbreviated, so that more reliance is placed on the profiles and interactional data. Finally, Application Study 3 forgoes entirely any examination of the interview and questionnaire item data and begins immediately with analyses of the profiles. Chapter 6 will discuss the merits of this use of the framework in reduced form.

APPLICATION STUDY 1: PARTNERS WHO DIFFER IN DOMAIN KNOWLEDGE

The two members of the first application study team are Mike and Dan, both males in the last semester of their undergraduate programs in Electrical Engineering. Both have 7 to 12 months of collaboration experience on engineering problem solving in various courses, but Mike has approximately 4 months experience in design work and Dan has about 9 months. Dan also has had military service that gave him considerable experience in the technical area of the team project. They are native English speakers, and they have had a long-standing friendship.

Problem Description

The goal of this team's project is to design and build a programmable function generator. With this generator, an operator is able to specify the wave characteristics of an electrical signal, including wave shape (square, triangular, or sine), frequency, amplitude, and duty cycle. The generator outputs the specified waveform to an external data acquisition device (here an oscilloscope) and sends the characteristics of the waveform (shape, frequency, amplitude, and duty cycle) to a liquid crystal display (LCD). The LCD readout and the readout at the oscilloscope must correspond within +/-0.5% at frequencies between 10 Hz and 1 MHz, with an amplitude not to exceed 20 volts peak to peak. In addition, the frequency generator must have an output impedance of approximately 50 ohms.

Interviews with Mike and Dan

The following are excerpts from the interviews with the participants. During the interviews, which were conducted about three-quarters of the way into their project, the participants were invited to speak openly about their project, their successes and setbacks, the relationship with their partners, the quality of team communications, and any team dynamics that helped or hindered their progress. (See Chapter 3 for a description of the interview environment and procedures.)

Mike Speaks

Regarding the Current Status of the Project: *We divided the project into two sections. Dan primarily took on the software. I'm doing the hardware, and I'm also incorporating the 6812 processor—just need a place to plug it in.*

I've burned up four chips. I've smoked them all. We're on hold until we get them. We're having problems with finding a stable voltage source. The chip is very sensitive to voltage. The DC source and voltage divider circuit are extremely dependent on what you put on it. It changes how much voltage it gives. It can't exceed 5.5 volts on any given pin or 50 milliamps of current. Voltage regulators are needed to stabilize. Then they would burn out the voltage regulators. We're now using a half burnt-out chip.

Dan's having problems interfacing with the LCD. He's opting to put out to a monitor. We're now trying to cut our losses. For the most part, we're doing okay. That one chip is hard to come by. The MAC 38 chip. At proposal time they were free. Four chips didn't come. They're still on back order.

From day one, we thought the problem would be easy. Especially Dan. I'm relying a lot on him with the software part because I'm not a software person. The hardware seemed real easy. [I thought] *all I have to do is make this work. That sounds all well and good, but then you have to find a stable power source to run the thing, and then all these* *other things that I hadn't anticipated. I'm using a 30 V power supply that every now and then just decides to put out 37 V.*

Regarding Knowledge Differences: *There's been a lot of "I don't know, Dan. Show me and explain it to me." He's real patient and meticulous in making sure every point is covered.*

Regarding the Advantages of "Ignorance": *I don't mean to put myself down, but I think that ignorance has its simplifying benefits. I think that I've provided a little "Here I don't understand. Let's do it a simpler way." I'm more or less a filter* [so that] *Dan doesn't talk way above my head a lot, except* [when he's talking about] *programming—then my whole mind glazes over. I would say "Hold it. Wait. Stop. Let's define each step." I think maybe I helped* [us] *examine the little steps involved. And some of the little steps got to be real big steps. I pulled us back down to real simple levels.*

Regarding Project Goals Versus Cognitive Detail: *Dan will get down here and start following a difficult trail, you know, and he may be looking at it at a very, infinitely small level or at the circuit level, but it may not have to do with our assignment. It may be a good idea, but a lot of our ideas were great ideas, but we had to abandon them for not being a part of the assignment.* [We had to ask,] *is it reasonable for us? We immediately started building like gangbusters on our project and we had all kinds of bells, whistles, lights, and sirens. We've had to narrow it down to functionality now.*

Regarding Differences in Project Perspective: *We came* [at the project] *from two different directions. The first thing I wanted to do was to buy the box we were going to put it all in and start putting our things on the outside. And then we would figure out how the thing would work* [on the inside]. *Dan kind of started from the other side. He knew more about what was going to be on the inside and was more focused on the inside. You can see the difference* [by comparing] *my drawings in the* [lab] *notebooks and his drawings. My drawings say "Here's what the front of the box is going to look like," and Dan's drawings say "And here's a little part of the circuit that we're going to have. This is how it's going to operate." So I think we came at it from two different angles. I was an outsider looking in and he was insider looking out.*

Actually, it has kind of worked both ways. Things I wanted to put on the outside . . . . of the box influenced the things Dan has to do.

Regarding Communication with Partner*:* *Dan and I are really good friends and I hope we continue to be good friends. We knew each other before the project. This friendship has helped our project some, I believe, in that I'm aware of his strengths and he's aware of mine. Communication has come real natural and been easy. Dan's real intelligent, and articulates what he means real well. I tend to have more trouble with it and I try to listen.*

Occasionally I wanted to take in information a little faster than Dan wanted to give it to me, and occasionally Dan wants to give me information a little faster than I can take it. [There's] *been a little bit of me "Dan, I don't understand." A lot of times I kind of felt like I was asking Dan to lead me. So I wanted to be a part, I wanted to put in—. It was a conscious decision on my part to try and occasionally put in something to say.*

Dan Speaks

Regarding the Status of the Project: *At the beginning*, [we thought all we had to do was] *get a chip that covers our range, then later figure the capabilities of the microprocessor. The function generator chip, that's the big question. Mike's doing most of the hardware, and then we're discussing it together. Getting parts is a problem. We're both ordering hardware, both talking and sizing.*

Both of us knew the functionality of the chip. We began to elaborate, wanting to go from 0.1 Hz to 40. There we got carried away. Things don't work as easily as we thought.

Tonight we're finishing up the code and turning in the project so far. Mike is still working on rebuilding a part of the circuit. He's got hardware that, well, sometimes it works and sometimes it doesn't. We have to take his wire from the function generator and plug it into the pin on the microprocessor. And it will work. Just wire to pin. A one-wire integration.

We're having problems with the LCD. It leaves characters off, although I can print out any message I want. It's a hardware thing. Only way to solve it is to scrutinize the details of the timing. I have an alternative method, [and that is] *to put it on a computer screen.*

Regarding Division of Labor: [We compared] *our constructs* [of the problem] *only at the beginning. After that we knew we were talking about the same thing.*

The project is big enough to split up. It's too big to work on together. Not practical. [We] *pretty much separated* [the project] *into what we know we could do. Mike's more into the hardware, I guess. I'm pretty decent with both the hardware and the software. In our case, I think, I had the advantage. I knew what he was working on, but I think he's afraid of coding.*

Mike would be happy to stay away from code. I knew that. I knew that before I ever became partners with him, and I don't mind that at all. I don't feel that that part is a big problem to us.

For me, I immediately think of both. I've had enough experience with similar things to know what kind of circuits to build and what kind of software to write. I have the general idea. It crystallizes [in my mind] *almost immediately as to what we have to do, but like any other project, your initial plan—it's going to change a little bit as you go from beginning to end.*

Regarding Differences in Project Perspectives: *The general thing is, I've done similar projects before in other classes, and some of the things I've done on the side, and so I assume I know exactly what they want. I don't know for sure, I just make that assumption. And I just jump right in there and I figure, okay, I know what they want and so we'll do it this way. And then Mike brings up the point that "Does this really mean what you think it means? Or do they want something completely different?" Sometimes he's right and sometimes he's wrong—you know?—but at least he brings it to my attention. There've been a few things where I've had to say "Okay I guess you're right, so we'll have to do it this other way."*

Regarding Differences in Basic Work Styles: *I think Mike is a little more meticulous than I am. I like to say I'm going to do this and this and this, and you do that and that and that, and then Mike will come in after and give all the details about what he's going to work on. Yeah, he wants to go over the details, go over everything. I think it's good to have the details for both people to know exactly what's going on. Otherwise, I'd be doing the coding part, he'd be doing the hardware part, and we wouldn't know what's going on with each other.*

Mike wants to draw it more than I do. I would rather work than do the paper work. There's a difference between putting it on paper and just scratching out an idea. Whenever I'm talking with anybody and I want to get a point across, a picture says a thousand *words. But* [that's just] *to get the idea down. Mike wants to get the final picture down. If we want to move a knob, he'll redraw the whole picture.*

For me [working toward a complete image of the goal] *is a really, really hard thing to do, just because of the process of going through the design, going through the research, finding things that don't work, trying something else—. For most of the things I've ever seen, nothing ever looks exactly the way you pictured it in the first place. So why picture it in the first place? Just work it until it comes out to something that does the right thing.*

I think it's really good to do that initial brainstorming and to think how it's going to look, [but] *it's just to have a goal in mind. I never see it as looking exactly like what we eventually build. And there's no sense in locking it in as "this is our final design," because it's never going to look like that.*

Design is like putting a puzzle together. A 1000-piece jigsaw puzzle. You can start in any corner, you can start at the edges, you can start in the middle, you know? You can put all these things, all these tiny parts, together and then bring it all together in the end. You don't need a flow chart to put a puzzle together.

Regarding Perceived Differences in Domain Knowledge: *I think he's got too much respect for my ability in a lot of things. You know? He kind of builds me up sometimes.*

Mike just thinks that I'm smart. I don't think I'm that smart. He likes to build me up more than is really necessary. I think that he just puts himself down too much. I think so. And I think that he's a hard worker, and I give him a lot of credit for that.

You know, he has done a really good job with the hardware so far. He's had a lot of problems with it, but I've had those same problems with it before with other projects, and I know where he is, you know, shaking his fist at the project. I've been there too.

Regarding Benefits of Friendship: *The biggest factor, biggest plus, is that we have both known each other for quite some time. We were friends to begin with. We knew each other's capabilities going in.*

Regarding Team Communication: *Our good communication definitely helps. Communication is good to make sure that everyone has a good overview. Everyone should know—no matter how many people are in the project—everybody should know at least the main points about each part of the project, if not the details.*

And that's the way it is with us. [Mike] *knows these are the main points about how the LCD works, the interrupts, and the kind of methods that I'm using. He just doesn't know any of the code that does it. Just the overview, you know, like the flow charts and stuff like that.*

Mike and I have had discussions on arguments. We both agree that an argument between two people consists of one person stating something, the other person giving a good thought about it, and responding to it, and making sure that the first person understands what they said, and then back and forth. You have the different parts, you have the sending, the receiving, the reply, and then the understanding of the reply and giving a proper reply from that.

There are people who are geniuses. They can do everything. Me, I don't' have that kind of memory. I need a network of people who can answer my questions. The bigger the project the more you need many people.

We have to be able to communicate so that we don't duplicate work and that all the work gets done. Those are the two main things. You have to be sure that you coordinate with each other. If one person can't do something then one person can take over.

Regarding the Need to Document the Project: *I feel as if I'm held back whenever I have to write. When they tell you that it has to be within three pages, and you need ten pages to say something, it doesn't say the same thing. It doesn't say what you know and what needs to be said. So you have to cut out a lot and you have to make it very brief. Yet they tell you to make it detailed. That causes confusion.*

To the observation that all arts and crafts have their constraints: *You call it art, I call it stress.*

To the question whether documentation altered his perceptions of the project: *I think writing the paper forced us to alter everybody else's perception of the project.* How so? *For one think, if you don't explain everything in detail, then they don't really know what you've gone through to come to this point.*

Regarding the Humor of Engineers: *We all have a common field around here, especially with all of us being electrical engineers. We've all studied in the same courses and everything. Most of my humor is specifically geared towards engineering stuff. If I made a lot of the jokes that I do over on the liberal arts side of campus, nobody would have a clue as to what I was talking about. But over here, you know, all my puns are built on Laplace transforms or field-effect transistors, and people understand them. I think that's the way most of the humor goes around here.*

Regarding Value of Project Experience: *Mainly the project gave me the experience of being an engineer, not just learning what an engineer has to know.*

One of my goals whenever I graduate is to start immediately on a book. I'm going to be writing a book on robotics.

Implications of Interview Data

According to their own words, the partners seem to be aligned in what they perceive to be the project goals and its difficulties, and they have a sense of their individual responsibilities. At least initially, Dan evinces a broader and deeper knowledge of the project, and Mike seems to give Dan the credit of better judgment on most matters, particularly anything to do with software. On the other hand, Mike wants to make his participation meaningful by seeking explanations and contributing energetically where he can. Thus he concentrates on the components "he can see," such as dials and circuitry, leaving to Dan the writing of code, to which Mike has an aversion. The partners are good friends, which is an important condition for mutual acceptance, the exchange of stress-relieving humor, and the maintenance of a lively transactional dialogue (Azmitia & Montgomery, 1993). Both are somewhat perfectionist in their personal standards and ambitious regarding the project scope, too much so in fact, for they have realized that they must simplify their project if they want to complete it.

Importantly, both partners seem to take Mike's relative inexperience as a potential asset. Mike feels free to ask questions, and the process of working out answers to those questions seems to flush out issues that had not been anticipated by either partner. At times Dan may "scaffold" Mike's learning processes. In addition, Mike's attempts to maintain a clear focus on the common ground of team knowledge—for example, through question-asking and revisions of project diagrams—perhaps represents a constraint on Dan, who may otherwise pursue his technical whims beyond what the project schedule allows. Of the two, apparently, it is Mike who persistently keeps the project goal in focus.

They both feel they are good communicators, and they have even discussed the structure and usefulness of healthy co-argumentation. This team is interesting, therefore, because the partners seem aware that they are attempting to overcome an imbalance in the partners' domain knowledge through the use of good team-communication practices.

Analysis of Questionnaire and Engineer Profile Data

The following subsections give analyses of the results for this team of the Engineering Task Preference Questionnaire (and its associated engineer profiles) and the results of the Project Satisfaction Questionnaire (and its associated profiles). In addition, the sections discuss possible implications of the results in regard to team problem-solving cooperative patterns.

Comparison of Engineering Task Preferences Results

Table 5-1 gives the item scores on the Engineering Task Preferences Questionnaire for this team. In general, Dan shows a higher level of interest across a range of engineering activities than does Mike. Dan's average score per item is 3.29 (out of a possible 4), compared to Mike's average of 2.58 per item, and the difference is significant ($t=2.73$; $df=23$; $p<.05$).

Mike gives his highest ranking (4) to only a seven of the listed activities. He seems to value the respect of others for both his technical and managerial abilities (*Q20 To have the respect of my colleagues on my technical ability* and *Q21 To have the respect of my colleagues on my managerial ability*). Yet, he registers low interest in activities that

TABLE 5-1
APPLICATION STUDY TEAM 1
ENGINEERING TASK PREFERENCES QUESTIONNAIRE RESULTS

Questionnaire Item		Mike [a]	Dan [a]	Overall Sample	
				Mean	SD
Q1	To help my company build its reputation as a first-class organization.	2.00	4.00	3.22	.76
Q2	To work on projects that have a direct impact on the business success of the company.	3.00	4.00	3.47	.66
Q3	To work on projects that interest me technically.	4.00	4.00	3.72	.51
Q4	To contribute to the business needs of the company.	4.00	2.00	3.15	.74
Q5	To work on projects that I have originated.	1.00	2.00	2.74	.89
Q6	To explore new and innovative technologies.	2.00	4.00	3.42	.76
Q7	To learn my job well and be able to stick to what I know.	2.00	4.00	2.95	.90
Q8	To work with others who are outstanding in their technical achievement.	2.00	3.00	3.20	.79
Q9	To work under capable management.	4.00	4.00	3.53	.65
Q10	To work on projects that incorporate advanced theories in my field.	1.00	4.00	2.85	.86
Q11	To manage the work of others.	1.00	3.00	2.54	.8905
Q12	To prepare and deliver oral presentations to upper management.	3.00	3.00	2.55	.97
Q13	To learn how the business is set up and run.	2.00	4.00	3.11	.92
Q14	To earn the respect of my colleagues on my managerial abilities.	3.00	4.00	2.72	.93
Q15	To become well-known outside my company as an authority in my field.	2.00	2.00	2.69	.98
Q16	To receive patents on my technical ideas.	4.00	3.00	2.63	1.06
Q17	To publish articles in technical journals.	3.00	3.00	2.16	.94
Q18	To present papers at professional societies.	2.00	2.00	2.08	.95
Q19	To be evaluated only on my technical competency.	1.00	3.00	2.23	.92
Q20	To have the respect of my colleagues on my technical abilities.	4.00	4.00	3.34	.72
Q21	To have the respect of my colleagues on my managerial ability.	4.00	3.00	3.04	.87
Q22	To have the required command of English to present myself and my ideas well.	4.00	3.00	3.63	.66
Q23	To work where requirements are clear.	3.00	4.00	3.17	.82
Q24	To eventually start my own business.	1.00	3.00	2.58	.96

[a] 4 = Very important; 1 = Not important at all.

involve the types of activities that actually earn those forms of respect. For example, he gives a score of 1 to *Q11 To manage the work of others* and to *Q10 To work on projects that incorporate advanced theories in my field*. Interestingly, Mike gives one of his highest ratings of 4 to *Q16 To receive patents on my technical ideas*.

Dan gives his highest rankings to activities dealing with high-profile company projects (for example, *Q2 To work on projects that have a direct impact on the business success of the company*), work in advanced technological areas (for example, *Q6 To explore new and innovative technologies* and *Q10 To work on projects that incorporate advanced theories in my field*), and knowing about (but not necessarily participating in) the business end of company operations (for example, *Q13, To learn how the business is set up and run*). Dan would rather have the respect of his immediate co-workers than a reputation outside his company (compare his score of 4 for *Q20 To have the respect of my colleagues on my technical abilities* with his score of 2 for *Q15 To become well-known outside my company as an authority in my field*). In summary, Dan seems to identify with the technological mission of the company, likes to explore interesting technical problems, and values the respect of his colleagues. He is least concerned about activities related to the larger community of engineers (for example, *Q18 To present papers at professional societies*).

The item showing the greatest difference in the partners' scores is *Q10 To work on projects that incorporate advanced technologies* (Mike: 1; Dan: 4). Other major differences appear in *Q6 To explore new and innovative technologies* (Mike: 2; Dan: 4), *Q7 To learn my job well and be able to stick to what I know* (Mike: 2; Dan: 4), and *Q19 To be evaluated only on my technical abilities* (Mike: 1: Dan: 3). In fact, Dan provides a higher rating for almost all technical activities than does Mike. Another general difference is that, while Dan shows consistency in his ratings, Mike's responses are somewhat contradictory, as when he seeks respect for his abilities in activities for which elsewhere he shows little interest in actually doing them. An interpretation of this difference is that Dan might have a clearer image of himself as an engineer and appreciation of what practicing engineers do. Mike, on the other hand, has not yet had enough positive design experience to see himself clearly as one exercising the craft of engineering.

Comparison of Engineering Task Preferences Engineer Profiles

Table 5-2 gives the Task Preferences Profiles for Mike and Dan. As Chapter 4 explains, the profiles represent aggregate scores of three item groupings, or factor categories, identified from the Task Preferences Questionnaire results. The categories are Management-Corporate, Microtechnical, and Higher Professional activities. As shown in Table 5-2, Dan has a comparatively elevated enthusiasm for Management-Corporate and Microtechnical tasks. In the Management-Corporation and the Microtechnical factor categories, his aggregate scores (3.36 and 3.50, respectively) are higher than the overall sample mean (3.04 and 3.15; $N=192$), whereas Mike's scores (2.82 and 2.00) are lower than the sample means. Dan registers his highest aggregate score in the Microtechnical group of items, which is where Mike registers his lowest score, and this difference is the only one that has statistical significance according to a paired samples t-test ($t=3.50$; $df=5$; $p<.05$), despite the small number of degrees of freedom. This tendency of Mike to devalue Microtechnical activities in his scheme of important engineering functions shows a decided diffidence toward technical aspects of engineering work and does not contradict the previous interpretation that Mike is keen on having respect from others, but is not yet clear about the path to gaining that respect. Dan, with his greater experience, shows a

TABLE 5-2
FIRST APPLICATION STUDY
ENGINEER PROFILES

Appl. Study Team	Profiles	Task Preferences Profile [a]			Project Satisfaction Profile [b]							
		Mgmt Corp	Mi-cro-Tech	Hi-Pro	Team Com	Ind-Tech	Team-Tech	Com Awr	Com Asst	Com Impr	Com Conf	Partic
	Sample Means	*3.05*	*3.15*	*2.52*	*3.27*	*3.03*	*3.04*	*2.32*	*2.13*	*3.19*	*3.13*	*3.60*
1	Mike	2.82	2.00	2.67	3.80	2.00	3.75	2.25	1.00	3.00	2.50	4.00
	Dan	3.36	3.50	2.83	3.80	4.00	4.00	2.00	1.00	3.33	4.00	4.00

[a] 4 = Very important; 1 = Not important at all.
[b] 4 = Very satisfied; 1 = Not satisfied at all.

general preference for Microtechnical activities, but that preference is only a shade greater than that for Management-Corporate activities.

Comparison of Project Satisfaction Questionnaire Results

Table 5-3 shows the partners' scores on the Project Satisfaction Questionnaire. Both partners give high ratings for most items having to do with team communication, for instance, *Q19 I feel that the quality of our work has depended largely on the ability of my partner and me to communicate well* and *Q31 Overall, I feel that my lab partner and I communicate smoothly and effectively*. Likewise, they both strongly disagree with *Q27 Most of the time, my lab partner and I have difficulty communicating.* The partners show differences, however, when the items relate to talking knowingly under pressure, as when the team is talking to the teaching assistant (for example, *Q15 When we're meeting with*

TABLE 5-3
FIRST APPLICATION STUDY
PROJECT SATISFACTION QUESTIONNAIRE RESULTS

Questionnaire Item	Mike	Dan	Overall Sample	
			Mean	SD
Q1 I'm self-conscious about my speaking ability when my partner and I discuss engineering topics.	1.00	1.00	2.11	1.09
Q2 During our discussions, my partner and I often have to clarify an idea by drawing a sketch or diagram.	3.00	4.00	2.55	0.98
Q3 I feel I could have worked more effectively alone.	1.00	1.00	2.00	0.97
Q4 The longer we work together, the better my partner and I are able to communicate.	3.00	4.00	3.30	0.79
Q5 Because of communication difficulties with my partner, I feel I sometimes have to compromise on what I think is the best technical course of action for our project.	1.00	3.00	2.12	1.00
Q6 I usually communicate better (in English) with my fellow engineers than with my non-engineering friends and acquaintances.	2.00	2.00	2.19	0.95
Q7 My ability to express myself generally improves when my partner and I converse on a social level.	3.00	2.00	2.99	0.86
Q8 Generally, as the course continues, I find that my partner and I are gradually adjusting to each other's communication style.	3.00	4.00	3.27	0.66
Q9 I feel that I have the technical competence to do the work in our project.	3.00	4.00	3.52	0.66
Q10 When I disagree with my partner on a technical issue, I sometimes go along with his or her opinion because I'm afraid I can't express my own opinion convincingly.	1.00	1.00	1.67	0.82
Q11 I prefer to concentrate on the technical or computational details of our project rather than the large theoretical concepts.	2.00	1.00	2.42	0.91
Q12 I am often confused by my partner's spoken English.	1.00	1.00	1.54	0.86
Q13 During our work, I frequently help my lab partner phrase his or her thoughts in clear English.	1.00	1.00	2.04	1.05
Q14 Our project has offered me a real opportunity to show what I can do.	4.00	4.00	3.00	0.86
Q15 When we're meeting with our TA, I make a special effort to "talk like an engineer."	3.00	1.00	2.45	0.92
Q16 I sometimes feel that my technical knowledge is inadequate for the project I've been assigned.	3.00	1.00	2.13	0.97
Q17 I feel that my partner and I accomplish more as a team than either of us could accomplish alone.	3.00	4.00	3.30	0.87
Q18 My partner and I have similar experience and backgrounds, so that neither of us has to coach the other on technical concepts.	2.00	2.00	2.51	0.99
Q19 I feel that the quality of our work has depended largely on the ability of my partner and me to communicate well.	4.00	4.00	3.12	0.89
Q20 My partner and I seldom engage in social discourse.	1.00	1.00	2.20	1.00
Q21 I usually let my lab partner speak for our project during discussions with our teaching assistant or adviser.	4.00	1.00	2.10	0.93
Q22 Our greatest communication challenge came at the beginning of our project, when we were trying to define our design problem.	4.00	1.00	2.94	1.03
Q23 There have been times when I felt my lab partner only pretended to understand what I was trying to say.	1.00	1.00	2.02	0.96

TABLE 5-3 (CONT)
FIRST APPLICATION STUDY
PROJECT SATISFACTION QUESTIONNAIRE RESULTS

Questionnaire Item	Mike	Dan	Overall Sample	
			Mean	SD
Q24 During our work together, I frequently help my lab partner put into words something he or she is attempting to express.	1.00	1.00	2.22	0.98
Q25 I speak much more fluently and freely when the TA is not present.	3.00	1.00	2.19	0.98
Q26 I tend to set the general direction and goals of our task and rely on my partner to supply the technical details.	3.00	1.00	1.53	0.79
Q27 Most of the time, my lab partner and I have difficulty communicating.	1.00	1.00	1.74	0.93
Q28 There are times when I only pretend to understand what my lab partner is saying.	3.00	1.00	3.60	0.64
Q29 I feel I have been able to participate fully in my team's decision-making.	4.00	4.00	1.60	0.89
Q30 I feel that at times my partner is confused by my spoken English.	1.00	1.00	3.41	0.71
Q31 Overall, I feel that my lab partner and I communicate smoothly and effectively.	4.00	4.00	2.25	0.96
Q32 Frequently, when we discuss the project with our TA, I find that I do most of the talking.	1.00	1.00	3.44	0.60
Q33 I have confidence in my abilities to communicate as an engineer.	3.00	4.00	1.62	0.83
Q34 Sometimes my partner and I give up trying to understand each other on a point and just go to another topic.	1.00	1.00	1.70	0.85
Q35 I sometimes know a better way to get a task done, but I'm unable to communicate my idea to my partner.	1.00	1.00	1.53	0.79

our TA, I make a special effort to "talk like an engineer" (M: 3; D: 1), *Q21 I usually let my lab partner speak for our project during discussions with our teaching assistant* (M: 4; D: 1), and *Q25 I speak much more fluently and freely when the TA is not present* (M: 3; D: 1). Mike seems to feel he must perform in formal settings, while Dan seems more relaxed and confident across the board. In keeping with this conclusion, Mike is more at ease when he and Dan are socializing (*Q7 My ability to express myself generally improves when my partner and I converse on a social level* (M: 3; D: 2)), and apparently, being friends, they engage in social talk frequently (*Q20 My partner and I seldom engage in social discourse* (M: 1; D: 1)).

For most items relating to team technical collaboration, both partners are again mostly in agreement. For example, both agree with *Q17 I feel that my partner and I accomplish more as a team than either of us could accomplish alone* (M: 3; D: 4) and strongly disagree with *Q3 I feel I could have worked more effectively alone* (M: 1; D: 1). Moreover, both partners felt they were able to play important roles in decision making; for example, they strongly agree with *Q14 Our project has offered me a real opportunity to show what I know* (M: 4;D: 4) and *Q29 I feel I have been able to participate fully in my team's decision making* (M: 4; D: 4). When considered together, these positive reflections on team collaboration indicate a productive team in which both members are fully engaged in the problem solving. On the other hand, Dan gives an indication that he occasionally must compromise on project issues to accommodate Mike's level of understanding: *Q5 Because of communication difficulties with my partner, I feel I sometimes have to compromise on what I think is the best technical course of action for our project* (M: 1; D: 3).

Differences between the two partners are greatest in items that relate to individual technical ability. To *Q16 I sometimes feel that my technical knowledge is inadequate for the project I've been assigned*, Mike indicates moderate agreement (3) and Dan strongly disagrees (1). Most suggestive of the team interactions to be expected during technical discussions are the partners' replies to *Q26 I tend to set the general direction and goals of our task and rely on my partner to supply the technical details* (M: 3; D: 1). These responses support evidence in the interview data that Mike is more active in the operational or mediational types of project tasks and Dan is more involved in technical and conceptual issues. Moreover, theses answers suggest that Mike takes the initiative in many interactions, even though he may not be adding much substance to the common ground.

Comparison of Project Satisfaction Engineer Profiles

The Project Satisfaction Engineer Profile (Table 5-2) displays the partners' differences in project-satisfaction categories and other parameters in sharper relief. Both partners rate the quality of their Team Communications high (M: 3.80; D: 3.80). This high rating complements the previous interview and questionnaire data that communication was a strong point of their work together. In addition, the high score in Team Communication suggests that for the most part the two members were well aligned in mutual understanding in most interactions. In the Individual Technical factor category, however, Dan's aggregate score is 4.0, which indicates supreme satisfaction with his own technical abilities in relation to the project, while Mike's aggregate score is 2.0, an indication of moderate dissatisfaction with his overall technical contribution. Both partners, however, are highly satisfied with overall team performance (Mike: 3.75; Dan: 4.00). Apparently, in the partner's efforts to meet project goals, good team communications has smoothed over any problems that might have come about because of asymmetry in technical knowledge or cognitive skills. Both partners are only moderately aware of themselves as engaged in any special form of engineering discourse (Communication Awareness), and neither feels any need to assist his partner in putting a thought into words (Communication Assistance). A difference appears, however, in the Communication Confidence factor category, where Mike shows himself to be neutral in his confidence in being able to engage in formal engineering discussions (2.5) and Dan shows himself quite confident in discussing engineering matters (4). For the Participation factor category, both partners strongly agree that they were able to participate fully in the project decision making (M: 4; D: 4). These latter high scores for both partners is a further indication that good communication practices must have been an important part of this teams work together.

Implications of Questionnaire Results for Team Interactions

The data from the Task Preference Questionnaire and its associated engineer profiles suggests that Dan may assume more dominant roles in interactions related to knowledge generation or interactions that direct the team toward solutions. The data from the Project Satisfaction Questionnaire and its profiles clearly indicate that the quality of communication in this team is high and that both partners were satisfied with their level of participation. On the other hand, both types of questionnaire data show that Mike is less inclined toward technical activities than Dan. The interviews make this disinclination explicit. Mike, therefore, may be more likely to assume roles that relate to inter-partner alignment and maintenance of common ground. If that is the case, then Mike may also be more likely to informate the system with question-asking and requests for explanations. At any rate, the bridge between partners seems to be their ability to communicate well.

Thus, both the interviews and questionnaire data indicate that Mike does not have the technical pre-knowledge to hold his own with Dan when conversing about LCDs, function generators, and the like. Consequently, co-construction and co-argumentation may not be prevalent in this team's discourse. When Mike does venture an idea in a Project Goal topic (and he says he attempts to assert himself when he can), in many cases Dan may elaborate the idea slightly beyond Mike's immediate grasp. Because Mike does not appear to be confident enough to challenge Dan, there may be considerable acquiescent co-elaboration (apparent or otherwise) in their Project Goal discourse. In Project Mediation interactions, however, Mike may be able to make important contributions. In those interactions he can help monitor the team's adherence to project standards, note inconsistencies, and bring important issues to the discussions. Most important, because he seems to be a good communicator, he may be a valuable agent for keeping the partners aligned. The next section will take a look at the interactions to determine how accurate these suppositions are.

Analysis of Selected Team Interactions

During the first three weeks of their project, Mike and Dan met several times a week to solidify their understanding of project requirements, schedules, and product specifications; block out an preliminary version of the function generator they are to build; and identify resources for materials and information. The following analysis focuses on interactions that (1) exemplify the partners' working relationship during discussions focusing on project goals and mediational matters or (2) seem critical to their overall project planning and decision making. For convenience, definitions of analytical terms and their codes are repeated in Tables 5-4 through 5-6 (see Chapter 3 for descriptions).

TABLE 5-4
DEFINITIONS OF INTERACTIONAL FOCUS CATEGORIES

Name	Definition
Project Goal	Focus is on the product or process representing the project goal state or any of its details. Includes subgoals, events, and milestones marking progress along the critical path.
Project Mediation	Focus is on the logistics, tools, procedures, resources, standards, and constraints that mediate the team's operations.
Project Team	Focus is on the team as a problem-solving unit and on its distribution of skills and knowledge in relation to the problem.
Off-Task	Focus apparently has nothing to do with the project.

TABLE 5-5
DEFINITIONS AND CODES OF INTERACTIONAL ROLES

Category	Role	Definition	Code
Conceptual	Proposer	Proposes an action or idea; proposes a solution of a problem or subproblem.	Prop
	Elaborator-Self	Expands and/or deepens one's own idea, decision, or proposal. Gives reasoning process for idea. (If idea is contested, see Justifier below.)	El-S
	Elaborator-Partner	Expands and/or deepens partner's idea, decision, or proposal. Supports reasoning. (If contesting the idea, see Critiquer below).	El-P
	Justifier	Like Elaborator-Self, but aim is to justify an idea that is contested or questioned.	Just
	Critiquer	Contests or questions the partner's idea.	Crit
	Explainer	Explains procedures, actions, physical processes, features/ functions of objects, etc. Aim is to provide information for general team needs.	Expla
	Analyst	Identifies/describes subproblems, discrepancies, inconsistencies, etc. Breaks down processes into steps. Usually *precedes* a proposal or decision.	Anal
	Presenter	Presents, names, and describes items in view. Topic can be pointed at.	Pres
	Reporter	Reports/describes previous or ongoing action or decision. Debriefs partner.	Rprt
	Partial-Informant	Starts an idea but fails to complete it.	PI
Team Regulation	Monitor-Standards	Relates to external standards, rules, procedures, instructions, etc.	Mon-S
	Regulator	Directs or regulates joint or individual action and decision-making. Directs action on a general task. Monitors conformance with past team (internal) actions and decisions.	Reg
	Implementer	Relates to actions or procedures to implement a specific decision or proposed solution (as opposed to a general task)..	Impl
	Specifier	Specifies a team need (material or informational) or the properties and characteristics of items (tool, component, material, etc.) for procurement.	Spec
	Evaluator-Resource	Evaluates data, component, instrument, catalog, etc. (or their sources).	Ev-R
	Evaluator-Self	Evaluates one's own ideas, work, experience, understanding, ability, decision making, or communications.	Ev-S
	Evaluator-Partner	Evaluates partner's ideas, work, experience, understanding, abilities, decision making, or communications.	Ev-P
	Evaluator-Team	Evaluates team ideas, work, experience, understanding, ability, decision making, or communications.	Ev-Te
	Evaluator-Task	Evaluates the task difficulty or problem solvability.	Ev-Ta
	Evaluator-Results	Evaluates the results of an action or decision.	Ev-R

TABLE 5-5 (CONT)
DEFINITIONS AND CODES OF INTERACTIONAL ROLES

Category	Role	Definition	Code
Interactional Alignment	Monitor-Align	Relates to mutual understanding and alignment in thinking. Verifies understanding or indicates lack of understanding.	Mon-A
	Explicitator-Self	Makes one’s own idea more explicit or emphatic, or states inferences from that idea to ensure mutual understanding in the immediate context of thinking. Makes explicit exactly what one is or is not talking or thinking about to ensure alignment or to differentiate from opposing idea.	Expli-S
	Explicitator-Part	Same as above but relates to the partner’s idea.	Expli-P
	Summarizer	Repeats old information (common ground) to ensure mutual understanding.	Sum
	Repeater-Self	Repeats one’s own words.	Rpet-S
	Repeater-Partner	Repeats the partner’s words.	Rpet-P
	Opener	Identifies the topic of the upcoming interaction or turn sequence.	Open
	Querier	Raises a topic for consideration.	Q
	Requestor-Info	Requests information.	Req-I
	Requestor-Opinion	Requests an simple opinion or choice from alternatives.	Req-O
	Requestor-Clarify	Requests that the partner clarify a statement or idea.	Req-Cl
	Requestor-Confirm	Requests for a sign of confirmation, agreement, or understanding.	Req-Cf
	Responder-Agrees	Responds positively to the partner.	Res+
	Responder-Neutral	Responds noncommittally to partner. Usually a continuer.	Res
	Responder-Disagr	Responds negatively to the partner.	Res-
	Responder-Opinion	Responds with an simple opinion or choice of alternatives.	Res-O
Other	Uncodable/Unclear	None of the above, or indecipherable.	Unc
	Digression	No apparent relationship to task, project, or team.	Dig

TABLE 5-6
DEFINITIONS OF COOPERATIVE FORMS [a]

Cooperative Form	Definition
Co-construction	Interaction is symmetrical and aligned. Partners are in agreement. Both build on each other’s ideas reciprocally and progressively.
Apparent co-construction	Interaction is symmetrical, but unaligned, and partners are in agreement. Partners’ proposals are non sequiturs. Partners do not share the same sense of each other’s contributions, though they may be stimulated by what they think they understand. They may be working in parallel.
Co-argumentation	Interaction is symmetrical and aligned, but partners disagree. Usually indicated by a proposal followed by a counterproposal of equal substance. Marked by justification and elaboration as both partners defend their positions.
Apparent co-argumentation	Interaction is symmetrical and unaligned. Partners disagree. “Arguing past each other.”
Acquiescent co-elaboration	Interaction is asymmetrical and aligned. Partners are in agreement. One partner generates ideas while the other gives feedback, responds with an opinion, shows agreement, or encourages the speaker to continue. Hogan et al. (2000) refer to this pattern as consensual.

TABLE 5-6 (CONT)
DEFINITIONS OF COOPERATIVE FORMS [a]

Cooperative Form	Definition
Apparent acquiescent co-elaboration	Interaction is asymmetrical and unaligned. Partners appear to agree, but there is a lack of mutual understanding. Feedback is off the mark or contradicts speaker, speaker does not respond appropriately to feedback, or speaker ignores feedback.
One-sided argumentation	Interaction is asymmetrical and aligned. Partners explicitly disagree, but only one partner is generating ideas.
Apparent one-sided argumentation	Interaction is asymmetrical and unaligned. One partner is generating ideas, and the other partner disagrees without understanding those ideas.

[a] See (Baker, 2002)

In the interactions presented below, the codes for interactional roles have been inserted, and they are explained in the paragraphs following each interaction. For a further discussion of the roles, cooperative forms, and their derivations, see Chapter 3. The cooperative forms, or patterns, are described by Baker (Baker, 2002).

Interaction 1: Choosing a Project Notebook

Throughout the early stages of the project, Mike is almost exclusively the initiator of both Project Goal and Project Mediation interactions; he raises topic after topic as he orients himself to the problem, project, and partner. In Interaction 1, one of the first recorded interactions, Mike shows Dan a number of different types of writing materials that can be used for the laboratory notebook. Some have graph paper, some have regular lines, and some are spiral bound, and so on.

(66-55)

M: Uh, I– we haven't talked, Dan, about lab notebooks? *[Open]*
D: Uh, huh *[Res].*
M: We're supposed to do a common lab notebook? *[Mon-S]* I have to have some that have copies for another class that I have *[Rprt]*. We don't have to have copies for ours *[Mon-S]*. I purchased five different kinds of notebooks– *[Rprt]*
D: –Okay *[Res]*.
M: –that I can use for various other classes, mixed and mingled *[Rprt]*, depending on what you want *[Reg]*. Uh, these are my most recent purchases *[Pres]*. Uh, your choice on how we do it *[Reg]*. A 321 notebook? *[Pres]*
D: Um-hmm *[Res]*.
M: I have another one that is basically a spiral side, that has the hep- hep-hex pattern on it? *[Pres]* For the grid pattern? *[Expla]*
D: The graph paper? *[Expli-P]*
M: And I have another one that folds up this way *[Pres]*. It's just regular lined *[Pres]*. Or we could just buy a regular lined notebook, just plain Jane? *[Req-O]*.
D: Okay *[Res]*.
M: Two of these? *[Req-O]*
D: Okay *[Res+]*
M: Would two do the same job as these? *[Req-O]*
D: We''ll we'll we'll ask the TA just to make sure *[Reg]*.
M: This this I got because it's just a graph paper thing *[Pres]*, but it's got– *[Unc; interruption].* Anyway, we can get a plain paper spiral, that's bigger? *[Req-O]*
D: Uh-huh *[Res]*.
M: Is that what you want to go to? *[Req-O]*
D: Yeah, yeah *[Res+]*.
M: Okay, okay *[Res]*.
D: Get a uh– *[Unc]* Wait, no, actually, I like the drafting *[Res-O]*. I don't want to have to go and paste it up *[Just]*.
M: Would two of these be, make you happy? *[Req-O]* or–
D: Yeah, yeah. *[Res]* Let's check with–
M: –because they didn't have any– *[Ev-R]*
D: –let's check with the TA first and make sure that he, whether he minds what we use *[Reg].*

Interactional Focus: The interactional focus of this early sequence is Project Mediation. The laboratory notebook is an continuously updated report of project ideas, decisions, events, resources, diagrams, and developments.

Interactional Roles and Cooperative Pattern: Mike initiates the sequence by tying the matter of the lab notebook to a course requirement (Line 3), and by doing so temporarily takes the role of Monitor-Standards. After reporting on what he has done, he becomes

Presenter as he shows Dan the various types of notebook materials he has collected (Lines 8, 12, and 14), and, as Regulator, states that the choice of notebook type belongs to Dan. Except for one turn as Explicitator-Partner (Line 13), Dan's contributions are primarily those of a Responder-Neutral (his "okay" is spoken more as a continuer than as an affirmative). At Line 20, however, Dan disrupts the pattern by taking on the role of Regulator himself and proposes that the team should delay choosing notebook material until they can talk to the teaching assistant. Mike sidesteps Dan's opinion and continues his presentation of alternatives in Lines 21-22. From that point on Dan is conflicted between indicating a preference at Mike's urgings and withholding a decision until they talk to the teaching assistant. From Line 21 to 26 Mike and Dan fall back into the earlier pattern until, in Lines 25 and 27, Dan finally responds with the opinion Mike is looking for. Mike, however, seems to want some surer sign of commitment from Dan (Line 29), whereupon Dan, reluctant to commit himself at this point, reverts to his earlier regulatory suggestion that they consult with the teaching assistant. The interaction ends with tacit agreement on that point.

In summary, the roles are as follows:

Mike: Opener; Monitor-Standards; Reporter; Presenter; Regulator; Explainer; Requestor-Opinion; Responder; Evaluator-Resource

Dan: Responder; Explicitator; Responder-Opinion; Regulator; Justifier

In this interaction, the speakers conflict in their Regulator roles. Mike wants a decision from Dan, and Dan wants to wait until the partners can confer with the teaching assistant. The interaction is asymmetrical in that Mike offers the preponderance of new information, and unaligned in that Dan's principal feedback in Lines 20 and 32 are out of phase with Mike's intent and in that Mike ignores Dan's feedback Line 21. There is no *explicit* disagreement, however, and the interaction is an example of Apparent Acquiescent Co-Elaboration.

Discussion: In this Project Mediation interaction Mike has taken it upon himself to assemble a number of notebooks styles. The notebook serves as a powerful cognitive tool, because, as a running record of the team's ideas, actions, and investigative results, it serves as a conceptual platform on which the team members (and any outsider) can keep up with the evolving design. Moreover, the notebook helps the team to maintain a global view—to see the relationship of the parts—of an evolving project design. For these reasons, Mike, who reports himself as less experienced than Dan in some technical areas, may see the lab notebook as an important tool for helping him keep in step with Dan.

Mike seems to have ceded to Dan the privilege of deciding which notebook style to adopt (see Lines 8-9). This deference is in keeping with Mike's high regard for Dan's opinion, as Mike reports in his interview. Note that he makes a hurried self-repair in Line 3, where he replaces "I" with "we." In addition, Mike often addresses his partner by name, whereas Dan seldom does so. Throughout the taped conversations, Mike seems to make an effort to use inclusive language, that is, to emphasize the "we-ness" of the team; in contrast, in many later passages Dan seems to take a first-person view of the project.

In addition, Mike seems to be quite forthcoming with the information he is willing to share with his partner, but his repeated role as Requestor-Opinion also indicates that he is trying to establish a two-way flow of information.

Interactional Sequence 2 and 3: Programming the Chip and Blocking out the Proposal

These two interactions are discussed together to illustrate Mike's somewhat scattershot approach to discussing the project. Although Mike initiates the majority of interactions in the early sessions, for the most part either he is reinforcing his understanding of topics already discussed or he is attempting to find locations in the problem space where he can best make meaningful contributions. Both of those motivations appear in quick succession in these two interactions. Dan, meanwhile, seems content to let Mike explore the issues at his own pace and simply provides feedback. Dan's expertise becomes obvious in later interactions that address problem solutions; for the time being, Mike has considerable latitude in raising topics of discussion.

(Interaction 2) (106-115)

M: Uh. Talking about using the 6812 *[Open]*.
D: Yeah *[Res]*.
M: And– I got to thinking about what needs to be programmed in there *[Rpt]*. Really all we have to do is program three functions *[Sum]*, right? *[Req-Cf]* Three mathematical things? *[Sum]* Simple get max, get max, how much time between maxes? *[Sum]*
D: Uh, um-kay *[Res+].* And then whatever's switched *[El-P]*.
M: Our register *[Expli-P]*.
D: Yeah, yeah *[Res+]*.

(Interaction 3) (116-131)

M: As it stands right now, Dan, I think I could probably start on the proposal *[Reg].*
D: Um-kay *[Res+]*.
M: Just to get a little block thing started *[Reg]*, you know? *[Req-Cf]* Titles with nothing written in them? [*Reg]* You know what I mean? *[Mon-A]*
D: Yeah, yeah *[Res+]*.
M: Then uh maybe we can start writing in the, developing, developing that at the same time *[Reg]*. You know what I mean? *[Mon-A]* At least in a block diagram type *[Reg]*.
D: Okay *[Res+]*.
M: You know what I mean? *[Mon-A]* Like go back to my 333T paper that I wrote a proposal in, look at it, and see how much of it I can use for *[Reg/Ev-R]*
D: Yeah, yeah. That sounds good. *[Res+]*

Interactional Focus: The interactional focus of Interaction 2 is Project Goal; the team is reviewing an integral operation of the final product. In Interaction 3, Mike abruptly changes the topic to discuss the team proposal, the first written report in the project. There the interactional focus is Project Mediation, since the partners are talking about project documentation, an adjunct to the project but whose composition is a valuable process for analyzing and consolidating project ideas.

Interactional Roles and Cooperative Patterns: In Interaction 2, Mike is Summarizer (Lines 3-5), because he is repeating ideas that the team has already discussed. As Responder, Dan agrees with Mike's summary and then, also in the role of Elaborator-Partner, adds an item to Mike's list of details (Line 7). Mike then explicitates by giving the name of the switching device (Line 7).

A summary of roles in Interaction 2 is as follows:

Mike: Opener; Summarizer; Requestor-Confirmation; Explicitator

Dan: Responder; Responder-Agrees; Elaborator-Partner

The only substantive role in this simple interaction is Mike's role of Summarizer. Besides the agreement he gives, Dan does little more than supply the name of the switching device. The interaction is asymmetrical in favor of Mike, both partners are aligned, and they are in agreement. The cooperative pattern, therefore, is Acquiescent Co-Elaboration.

In Interaction 3 Mike takes the role of Regulator by assigning himself the responsibility of starting the proposal (Line 1) and explaining how he will manage the task (Lines 3 and 4; 9 and 10). In Lines 6 and 7, his Regulator role shifts focus somewhat to include activity of both partners. The summary of roles is as follows:

Mike: Regulator; Requestor-Confirmation; Monitor-Alignment; Evaluator-Resource

Dan: Responder-Agrees

Interaction 3 is asymmetrical because Mike, as Regulator, introduces all the new ideas in the interaction.. The partners are in agreement, and they are aligned. The interaction is again Acquiescent Co-Elaboration.

Discussion: In these two interactions, Mike raises two apparently disconnected topics in succession, as if he were going down a mental list of personal issues. This desultory pattern prevails throughout the early sessions and at the beginning of later sessions. The interactions are usually short, and they move abruptly back and forth between Project Mediational and Project Goal topics. Mike seems to have a purpose, however, in bringing such a diverse range of topics. In these interactions, for example, Mike may have an immediate reason for bringing up these two apparently unrelated topics in quick suggestion. First, he assures himself that he understands a technical aspect of the project design, and only then does he volunteer to block out the written proposal that will describe that aspect. Later, once he has written that portion of the proposal, he will have stabilized a basic aspect of the design, at least in his mind.

In these interactions, Mike speaks tentatively with the rising inflection of a question-asking. Here and there he checks Dan's understanding with a direct question ("You know what I mean?" in Lines 4, 7, and 9). These requests for confirmation and his role as Monitor-Alignment seem to indicate the importance to Mike that the partners maintain clear communications and alignment in thinking. Dan does not adopt those roles so frequently.

In these interactions, Dan's contribution has been limited to agreement and a corrective word or two. As stated before, he seems content to let Mike set the agenda for discussion, and this latitude allows Mike to "poke around" issues in his own time and in his own way. As in Interaction 1, Mike shows clear signs that he has internalized information from previous sessions (Interaction 2, Line 3), and now he turns to Dan for confirmation that he is on the right track. In effect, he is mapping his understanding to that of Dan's. The process is salutary, because even though the information is not new to the team's knowledge base, it aligns and tightens up the partners joint understandings and gives Mike the opportunity to adjust his knowledge structure through natural processes of assimilation and accommodation. Interestingly, the process that Mike is using to understand the project is dictating the approach the team is taking to the problem, namely, repeated sweeps through the project issues, each sweep potentially ferreting out something new or contradictory. For that reason, Mike, through his repeated efforts to keep himself aligned with Dan and his effort to keep information in the open (where it can be appropriated), effectively inculcates a variety of team learning processes.

Interaction 3 gives further evidence of Mike's interest in any type of project inscription, such as the proposal, project notebook, and block diagrams, that help him keep project details in perspective. He seems most keen on aspects of the project that can be made visible; for example, he says in a later interaction

M: What I'm envisioning, Dan?
D: Um-hmm.
M: Is something like ( ) I want a finished box in my mind, plus the amplitude, forget where it's all attached to. I'm just thinking of what the face of the box is going to look like? Right? . . . .
D: Yeah, yeah.

Given that Mike's interview and engineer profile suggest a lack of self-confidence in his technical prowess (as compared to Dan's), his interest in writeups, visuals, and other inscriptions could well stem from a metacognitive strategy, conscious or not, to keep abreast of the evolving project. The inscriptions identify product components and stabilize their interrelationships. They represent a culmination of the ideas on which the partners have concurred up to a given point, and consequently they are visual and verbal manifestations of the team's common ground of understanding. Dan, on the other hand, states in his interview that he relies on his inner sense of the problem requirements, and he is not so prone to depend on early depictions of the final product because, as he says, "Nothing ever looks exactly the way you pictured it in the first place. So why picture it in the first place?" Nevertheless, he makes no objection to Mike's insistence on having drawings and writeups, and, as later interactions show, Dan himself frequently resorts to a quick sketch to work out circuit details.

Interactions 4A and B: Criteria for Selecting an LCD

As previously mentioned, not least of Mike's sources of information is Dan himself. Because Mike seems to be mapping his understanding to Dan's, many interactional strings consist of Mike simply asking Dan questions. (In fact, nearly every contribution from Mike in the Project Goal area of topics is in the form of a request for information or an opinion.) Dan accommodates himself to Mike's interrogation, but he often is not sure of what Mike is asking. Mike consistently has problems articulating questions about topics in which he is not yet familiar. As a result, the partners are frequently unaligned in many of their conversations.

Interaction 4A (691-740)

M: Uh-hmm. *[Unc]* What exactly am I looking for on an LCD? *[Req-I]* I'm looking for it to operate in a certain way? *[Req-I]*
D: Uh, we we want, we want something that gives us information *[Spec]*. We want something that gives us information on uh on how to program it, how to use it *[Spec]*.
M: Oh yeah, of course *[Res+]*, but– *[Res-]*
D: –Okay, if it doesn't have anything like that *[Ev-R]*, then we don't want it *[Reg]*, because we don't want to sit there and try to figure out all the pin ins and pin outs *[Just].*
M: Okay *[Res]*. So, but what are we looking for in pin in and pin out stuff? *[Rpet-P/Req-I]* We want–*[Unc]*
D: Uh *[Res].*
M: We, we– It's going to take in a digital thing from the 6812– *[Sum]*
D: Yeah *[Res].*
M: –and it's going to output words on a screen *[Sum]*. Uh, I mean I don't know what I– *[Ev-S]*. Am I looking for particular voltages? *[Req-I]*
D: No *[Res-].*
M: –particular impedances? *[Req-I]*

D: Uh, we're not looking for anything in particular on that *[Reg]*. Uh, it'll it'll have any number of pins *[Expla]*, you know, just whatever it takes to program it *[Expla]*. You know, it's not, won't be programmable like a microprocessor or anything *[Expla]*, but what I mean by programming *[Expli-S]* is, when you send uh 8 bytes to it in parallel? *[Expla]*

M: Okay *[Res]*.

D: –it will do a certain thing *[Expla]*, and then uh– or maybe uh certain pins are supposed to have higher voltages and certain ones are supposed to have lower voltages *[Expla].* And then– when you toggle them? –that's what sends data serially to it? *[Expla]*

M: Okay. *[Res]*

D: Um-kay. *[Res]* All that should be described in the information that comes with the LCD– *[Ev-R]*

M: Okay, so I'm looking for something that maybe has 16, 40 pins on the back of it? *[Req-I]*, Right? *[Req-Cf]*

D: Ye::ah *[Res]* I don't uh– *[Unc]* For a, for a much fancier LCD display? *[Req-Cl]* Now actually actually each each one is going to have some circuitry with it. *[Expla]* Okay, actually on the screen itself. *[Expla]*

M: Okay *[Res]*

D: Okay *[Res]*. Uh, that's what we're going to want *[Reg/Spec]*. Uh, as a matter of fact, I'll take you over in take a look at one with Mary. *[Reg]* I'll show you what the LCD displays over there look like. *[Reg]* If you check one out, we'll program one of those. *[Reg]*

M: Okay *[Res+].*

(Break in dialogue. Interaction continues at another location, the counter of the parts bin. Extraneous remarks to, from, and among other speakers in the vicinity have been removed except as noted.) (1341-1445)

Interaction 4B (1320-1399)

D: I think this is the only kind that they've got *[Pres/Ev-R].*

M: So it just has what, like ten pins or something? *[Req-I]*

D: I think so, yeah. *[Res+]* I hope they have another kind that's a little bit, uh little bit less complicated than this one *[Ev-R].* Yeah, you just take these pins *[Pres]* and you just uh read up on the document on this thing *[Reg]*

[Interruption]

D: See this has fewer pins *[Pres].*

M: Fewer pins *[Rpet-P].*

D: Actually, I can't tell *[Ev-S].* Might be the same, but it's a lot smaller *[Pres].* This one is programmable *[Pres].* Actually, look at this one *[Pres]*. This one's got enough uh enough things on there *[Pres]*

M: Ohhh. *[Res]*

[Interruption in which Dan asks Parts Manager whether she has another LCD like the one they are examining. Dan indicates that the LCD they have in hand may be suitable for their project. Dan then continues explaining the LCD operation to Mike, as below.]

D: And see, what I was saying was, there's your LCD right there *[Pres],* but they all have some kind of components and stuff on here that make it work *[Expla].*
M: Well, see we can–*[Unc]*
D: And uh and this is what, kind of what you call programmable *[Pres/Expla]* because you can send certain information to the pins *[Expla]*.
M: Okay *[Res].*
D: And once you send the information to the pins, it sets it up, it sets up a display for one line, two lines, and the different lines and sizes and everything *[Expla]*.This sets things up for you *[Expla].*
M: Okay *[Res+]* But this, but this has got this up here *[Pres]* and we can make this copy *[Reg]*, but also I can write down on this thing that it is a DMC20481, 20 characters times 4 *[Impl]*.
D: Yeah *[Res+]*

Interactional Focus: The focus of both Interaction 4A and 4B is Project Goal. The liquid crystal display (LCD) is an integral part of the design product and the team wants to examine one to investigate its operation.

Interactional Roles and Cooperative Patterns: In Interaction 4A, Mike (as Requestor-Information) asks Dan about the parameters for specifying an LCD (Lines1-2). He seems surprised when Dan, assuming the role of Specifier, ties the selection of an LCD to whether or not it is accompanied by programming information (Lines 3-4). Mike's partial turn in Line 5 is a cue that the existence or nonexistence of programming information does not bear exactly on what he was expecting. Dan ignores the cue and continues on to explain that the programming information should describe the "pin ins and pin outs" (Lines 6-7).

The pins Mike can understand (he can see them), and as Requestor-Information (Line 8) he appropriates Dan's terminology ("pin in and pin out") as a starting point to refining his question. As Summarizer he tries to situate his understanding in the context of what they both know (Line 11 and 13), as Evaluator-Self he states that he does not know what he is looking for (Line 13-14), and then as Requestor-Information he mentions a few familiar physical parameters for selecting an LCD (Lines 14 and16)—all perhaps in an attempt to skirt the topic of programming "stuff" and limit Dan's response to the parameters that Mike is more familiar with. In Lines 15 and 17, Dan (Responder-Disagrees) indicates that he and Mike are not aligned. His reaction to the misalignment, however, is further explanation (Lines 17-20 and 22-24), which provides only more of the type of information that Mike is not finding helpful. Mike, still avoiding direct engagement with the programming aspects of LCDs, refocuses on the number of pins the LCD should have (Lines 28). To Dan, however, the number of pins is somewhat beside the point (indicated by the prolonged and doubtful "ye::ah" in Line 30). As Explainer he describes the circuitry as the aspect of the LCD they should be concerned about. Finally, in Lines 34-36, Dan (as Regulator-Task) hits upon the idea of showing Mike an actual LCD and explaining its operation then. To that the partners agree.

Below is a summary of each partner's roles in Interaction 4A:

Mike: Requestor-Information; Responder-Agrees; Responder-Disagrees; Repeater-Partner; Summarizer; Responder; Evaluator-Self; Requestor-Confirmation

Dan: Specifier; Evaluator-Resource; Regulator; Justifier; Explainer; Regulator; Responder; Responder-Disagrees; Explicitator-Self; Evaluator-Resource; Requestor-Clarification;

It is clear that Dan is supplying the substance of this interaction, and his roles are major: Specifier, Evaluator-Resource; Regulator, and, most frequently, Explainer. The interaction, therefore, is asymmetrical. The partners appear unaligned in their thinking, with Mike asking about the LCD in terms of physical parameters and Dan answering in terms of programming information and circuitry, the features that Mike "cannot see." The question of agreement is somewhat complex. Mike implies disagreement in Line 5, though it may be based more on Mike's perception that Dan has misunderstood his question than on any belief that Dan's answer is incorrect. Likewise, Dan's disagreements in Lines 15 and 17 are in direct response to requests for an opinion rather than any positive statement. On balance, therefore, it would appear that there is no overt disagreement between Mike and Dan. They are just talking at cross purposes. Consequently, the discourse in Interaction 4A is asymmetrical, unaligned, and in agreement. The cooperative form in that case is Apparent Acquiescent Co-Elaboration.

In Interaction 4B, the team has moved to another location, the counter of the parts bin, where the parts manager and bystanders are present. Despite interruptions and digressions, the interaction continues from Interaction 4A. Dan, as Presenter (Line 38), initiates the interaction by showing Mike an actual LCD. Mike, whose understanding of LCDs at this point seems to be anchored on pins (Line 39), follows Dan's explanation of the operation of the LCD with neutral responses. They examine more than one type of LCD until they find one that might serve their needs (Line 47). After an interruption to inquire about obtaining a similar LCD, Dan continues his explanation, and Mike's neutral responses are more or less continuers. The pattern of discourse changes in Line 63 when

Mike discovers the serial number on the LCD they are examining. The serial number enables them to order the LCD for themselves. It is not clear,. However, that Mike knows any more about selecting an LCD suitable for this or any other project, but having the serial number of one that Dan has indicated might work for the project seems to satisfy Mike's curiosity about LCDs for the moment.

From Lines38 to 63 in Interaction 4B, the distribution of roles is as follows:

Mike: Requestor-Information; Repeater-Partner; Responder-Neutral; Responder-Agrees

Dan: Presenter; Responder; Evaluator-Resource-Agrees; Regulator; Explainer

Thus, in Interaction 4B, the partners are asymmetrical in favor of Dan, but they are aligned and in agreement. The cooperative form, therefore, is Acquiescent Co-Elaboration. In Lines 63-66, however, the pattern changes. There Mike assumes the role of Presenter, Regulator, and Implementer, while Dan is Responder. For this short section, the pattern again is Acquiescent Co-Elaboration, but with asymmetry favoring Mike.

Discussion: In Interaction 4A, there are two intersecting axes to the conversation, and each speaker is revolving around a different one. Mike is speaking of the LCD as a hardware item with shape, function, tangibility, and physical requirements—an object to be incorporated into the overall system. Dan is speaking of the LCD more in the abstract, as an object that must be programmed to behave in desired ways. The axes intersect on the word "pins," where Mike comes a little closer to Dan's way of thinking. From there, however, Mike veers off into asking about the number of pins, another concrete aspect of the LCD, whereas Dan is looking for an LCD (of whatever number of pins) with information about its coding. To Dan at this point, the number of pins is relevant, but immaterial.

While Mike is generally an able speaker in the team dialogues, he tends to be somewhat imprecise in his terminology. For example, he resorts to vague works like "thing" and "stuff." Nevertheless, he *attempts* to co-construct knowledge with Dan by making explicit what he does know or thinks he knows. For example, he frequently follows his requests for information with a stab at answering his own question (see Lines 14 and 16). In that way, he reveals how his knowledge structure is oriented so that Dan can shape his answers to Mike's current understanding. In this case, Dan's response is simply to suggest that it would be best for him and Mike to look at an LCD together.

At the counter a bit of serendipity occurs. While describing several LCDs to Mike, Dan discovers one that may work well in their project, a stroke of fortune that Mike seizes upon to curtail any further discussion about programming. Nevertheless, as often happens with peers working together, the processes of instruction and discovery often become one (Rogoff, 1990).

Interaction 5: Fine Adjustments and Linear Error

As the project proceeds, Mike and Dan become more balanced in their Project Goal interactions, but never to the extent that they are truly co-constructive or co-argumentative. Rather, the partners take turns taking the dominant role in Acquiescent

Co-Elaboration patterns. Even so, the style and efficiency of their communications are quite different. Dan has no difficulty making himself understood, but much of any interaction that Mike leads is a painful search for the right expression. On the other hand, as the following sample shows, Mike is not afraid to contribute new ideas when he can. When he does so, moreover, he tends to frame his ideas within the current knowledge structure of the team, and where there is a discrepancy in mutual understanding, he tries to make that discrepancy explicit before working out its resolution.

Although the excerpt given below is divided into four parts for analysis, it represents a continuous string of turns and is considered a single interaction.

Interaction 5 (2762-2840)

(Sequence 5A)

M Okay, the fine adjust that you're talking about? *[Open]*, I thought it'd be internal, um, an internal adjustment *[Mon-A]*. If uh, assuming we have linear– *[PI]*. Okay, we could– *[PI]*

D –It won't *[Res-]*, I'm not, I'm not going to make that a um an internal adjustment *[Reg]* because what if someone needs exactly um 69.9 hertz *[Just]*, okay? *[Req-Cf]*

M Mm-hm *[Res].*

D And uh, and we can't make this thing accurate with these resistors on this dial *[Just].* But what if-? *[Unc]* We can't make it so you can dial exactly 69.9 hertz on there *[Just].* You need, you need some other adjustment to raise it up like from 69.5, 69.6, all the way up to 69.9 *[Just].*

M Okay, then *[Res+]*. I understand exactly what you're saying *[Mon-A]*. I concur *[Mon-A]*.

(Sequence 5B)

M Then, I think we should uh *[PI]* What I was talking about as being an internal thing? *[Expli-S]*

D –-Mmm-hmm *[Res].*

M If we find that there is some linear error in what we dial in here– *[Anal]*

D –-Uh-huh *[Res].*

M versus what goes through the function generator and what it produces– *[Anal]*

D –Uh-huh *[Res].*

M –if there's some linear error *[Anal]*, we can put series resistance in *[Prop]*, like a 20 meg and a uh uh POT to dial in *[El-S]*, so this corresponds one to one with what comes out *[Anal]*.

D Okay *[Res+]*.

M Okay? *[Req-Cf]* Now what you're talking about is another knob here, a one's place that is just a fine tune adjustment *[Expli-P]*.
D Right, right *[Res+]*.
M I was thinking about the linear error thing being internal *[Expli-S]*.
D Yeah [Res+].

(Sequence 5C)

D: You're saying there's errors in this resistance box here *[Opener/Expli-P]*. We'll have to put something uh in line with some of these resistors *[El-P]*. That's the only way that we'd be able to fix that *[Ev-T]*.
M Okay *[Res]*. What–*[Unc]*
D –you know if there's, if there, if this isn't exactly linear– *[PI]*
M –Okay *[Res].* I'm not worried about this being linear *[Pres/Expli-S]*. I'm talking about the translation between– *[PI]*. All right, so the way I understand it– *[PI]*
D –Uh-huh *[Res]*.
M Okay, let's say, we, the volt, no, we use the resistor control function generator *[Anal]*. Okay? *[Req-Cf]* The resistance control function generator isn't going to say "If you have one ohm of resistance, we'll give you one hertz of a sine wave" *[Anal].*
D Right *[Res+]*.
M Okay, it might say if you have 100 ohms of resistance, then we'll give you a one *[Anal]*. Or if you have uh, you know, 17.295 ohm resistance, we'll give you one hertz *[Anal]*. Okay, that's what, if that error is linear, in other words, you know we can somehow– *[PI]* When we dial in here, we're saying one hertz, we're not saying one ohm *[Anal]*. So in series with this, in my mind, there would need to be a fixer *[Prop].*
D Okay *[Res+]*.
M Okay, a scaler or whatever *[El-S]*.
D Yeah *[Res+]*.
M –or make it what we need the resistance to be *[El-S]*.
D Yeah *[Res+]*.
M Hopefully, that will be a linear thing *[Anal]*.
D We're going to need something like that *[Reg]*. You're right *[Res+]*.I didn't understand what you were talking about before *[Mon-A]*.
M Okay *[Res]*.
D I know exactly what you're talking about now *[Mon-A]* and uh, I didn't even think about how we were going do that *[Ev-S]*. I knew that we had to but I didn't think about how *[Ev-S]*.

Sequence 5D

D We're going to have to set up *[PI]*–. Actually it's going to be a voltage division *[El-P]*, so we're going to have, um, to figure out how to do this voltage divider using this thing *[Reg/Anal]*, maybe using some kind of um resistance bridge *[Anal]*. That's probably what we're going to end up having to do *[Reg/Impl]*.
M Okay [*Res+]*. Yeah, I, so you're already further along about that than I am *[Ev-P]*. I'm just hoping that– *[Unc]*
D –Yeah *[Res]*, if you want me to jot down in the book real quick– *[Impl]*
M Yeah *[Res+]*

Interactional Focus: The focus of Interaction 5 is Project Goal. The discussion centers on a fine-adjustment feature of the function generator, and the partners initially differ in their understandings of what the fine adjustment is supposed to do. For Dan there needs to be a fine-adjustment capability for "tuning" the generator to yield an output of a stipulated precision. For Mike there needs to be fine adjustment to compensate for system-induced error.

Interactional Roles and Cooperative Patterns: An overview of this interaction is as follows:

Sequence 5A (Lines 1-11): Mike (Monitor-Alignment) points out a conflict in his and Dan's interpretations of the fine-adjustment feature (Lines 1-2). Dan (Justifier) responds by explaining his reasons for deciding on an external dial (to give the operator a precise means of designating system output) (Lines 4-5 and 7-10). Given Dan's interpretation of the fine adjustment Mike agrees (Line 11). In the next stage, however, Mike describes his own version, and it is Dan who is not aligned with Mike. For this first sequence of the interaction, however, the roles are as follows:

Mike: Monitor-Alignment; Responder

Dan: Responder-Disagrees; Justifier

The exchange so far is asymmetrical in favor of Dan, who contributes the only new information, both partners are aligned in that Mike understands Dan's point of view and agrees with it, and Dan has yet to hear Mike's point of view. The cooperative pattern is Acquiescent Co-Elaboration with Dan the primary informant.

Sequence 5B (Lines 12-27): Mike (Analyst) now explains (Lines 15, 17, and 19-21) what he means by an internal adjustment (a way of compensating for error incurred within the function generator itself) (Lines 16, 18, and 20-22). Mike concludes his analysis with a proposal for some form of "series resistance" (Line 20), and Dan agrees. To sharpen the contrast between the partners' thinking and perhaps to strengthen their alignment, Mike (Explicitator-Partner and -Self) reiterates both his and Dan's interpretations of the fine adjustment (Lines 24-25 and 27). Dan agrees with Mike's recapitulations, but when he himself restates Mike's position in Line 27 (see next sequence), he reveals that he is not quite in line with Mike's thinking. The roles in this second sequence are as follows:

Mike: Explicitator-Self; Analyst, Proposer;Elaborator-Self; Requestor-Confirmation; Explicitator-Partner

Dan: Responder; Responder-Agrees

In this sequence, Mike provides the new information. The exchange is asymmetrical in favor of Mike, but the partners are not aligned, even though they are in agreement. The cooperative form, therefore, is Apparent Acquiescent Co-Elaboration, with Mike the primary informant. The next sequence makes clear that the cooperative form is only apparent.

Sequence 5C: When, in Line 29, Dan (Opener/Explicitator) draws an inference from Mike's proposal in Line 20, Mike sees that Dan has jumped to the wrong conclusion (or Mike has not made himself clear) about what Mike means by "linear error." To Dan, the error that Mike is talking about is in the resistor box (Line 29). In Lines 34-45, therefore, Mike (Analyst) attempts to explain that the error he is talking about is a product of the translation between what is dialed in (in ohms) and what the function generator produces (in hertz).Mike concludes his analysis by re-expressing his proposal for the inclusion of a "fixer" to compensate for any systematic scaling error (Line 45). Dan agrees with that proposal, and as Monitor-Alignment he finally indicates his understanding of Mike's idea (Lines 50, 53). At that point, both partners seem to feel that they have a joint understanding of linear error and fine adjustment. The summary of roles for this sequence is as follows:

Mike: Responder; Presenter/Explicitator-Self; Analyst; Requestor-Confirmation; Proposer; Elaborator-Self

Dan: Opener; Explicitator-Partner; Evaluator-Task; Responder; Responder-Agrees; Regulator; Monitor-Alignment

The sequence is asymmetrical because all of Dan's contributions are in reaction to Mike's analysis. Though the impetus of the sequence is Mike's awareness of a misalignment between partners (which was not apparent in the preceding sequence), Dan and Mike are aligned for the duration of this sequence, and they are in agreement. The cooperative form of the sequence is Acquiescent Co-Elaboration.

Sequence 5D : Having understood Mike's meaning, Dan (in quick succession, Elaborator-Partner, Implementer, and Regulator) elaborates Mike's proposal by identifying the component whose function Mike has described and suggesting a course of action to implement the solution (Lines 58-61). Mike (Evaluator-Partner) observes that Dan has aggressively appropriated his idea and in fact seems to be carrying it beyond Mike's current understanding (Line 62). Dan (Implementer) volunteers to draw the new schematic in the laboratory log. The summary of roles in this sequence is as follows:

Mike: Responder-Agrees; Evaluator-Partner

Dan: Elaborator-Partner; Regulator; Analyst; Implementer

The cognitive load shifts back to Dan once he is clear about what Mike is proposing. The partners are aligned and in agreement, and the cooperative form, once again, is Acquiescent Co-Elaboration.

Discussion: When Interaction 5 is viewed as a whole, its overall cooperative form seems at first to be Apparent Co-Argumentation: first Dan gives his interpretation of the fine adjustment and then, with more difficulty, Mike gives his interpretation (which calls into play the notion of linear error), and they then find that they are “arguing past each other.” Actually, there is no argumentation at all; Mike’s proposal is not a counter to Dan’s, but another issue the team must consider. To disentangle the two issues, both partners, and especially Mike, take the role of Explicitator frequently, but with particular effect in Lines 24, 27, and 29. The role of Explicatator is useful to team coordination because it foregrounds the partners’ ideas and holds them up for examination and comparison, with the result, as in this case, that any discrepancy in thinking becomes quickly obvious. As it turns out, the partners are actually in agreement throughout the interaction, but out of alignment in the second sequence. The basic cooperative form of the interaction is again Acquiescent Co-elaboration.

This is one of the few of the early interactions in which Mike makes a substantial Project-Goal contribution. After Mike manages to articulate his idea, however, Dan picks up the idea and carries it forward a bit too fast for Mike’s comprehension. The process is an opportunity, however, for Mike to observe how one of his major ideas can be implemented into the design.

Conclusion of Application Study 1

The Task Preference questionnaire data for this team suggested that the member interactions would be asymmetrical in Project Goal topics, with Dan taking the more dominant roles and supplying the more substantive information. On the other hand, the interviews and Project Satisfaction data indicated that both partners were pleased with the quality of their team communications and level of participation. Thus, while symmetry may be lacking, the partners were able to maintain a sufficient degree of alignment and agreement to carry on productive discourse. Consequently, as the interactions show, the primary pattern of cooperation is Acquiescent Co-Elaboration (representing the combination of asymmetry, alignment, and agreement). The following summarizes how these elements of interaction manifest themselves in the team's problem solving discourse.

Symmetry: In Project Goal interactions, Mike typically takes Interactional Alignment roles such as Summarizer or Requestor (for Opinion, Information, or Confirmation). Though he may initiate interactions, his usual aim is to obtain Dan's confirmation, opinion, or clarification. Dan, on the other hand, takes on a wider range of both Conceptual roles (such as Elaborator, Justifier, Proposer, and Explainer) and Team Regulation roles (such as Regulator, Implementer, Specifier, Evaluator). Dan is not as likely to engage in Interactional Alignment roles as Mike. In Project Mediation interactions, Mike (as Presenter or Reporter) is more likely to provide information for team consideration. For example, as Monitor-Standards he regulates team conformance to task requirements and team consistency with previous decisions; however, his proposals are limited to procedural matters rather than discovery. Dan is less inclined to offer proposals in Project Mediation topics unless they relate to the specification of resources and components.

Alignment: The most powerful force for team alignment in both Project Goal and Project Mediation interactions is Mike's activity in Interactional Alignment roles, such as Summarizer, Explicitator-Self and Explicitator-Partner, Monitor-Alignment, and the various Requestor roles. Those roles not only served Mike as checks of his understanding against the understanding of Dan, but served both partners in testing and augmenting the common ground wherever the partners discovered differences in perspective or the use of terminology. As in Interactions 4 and 5, Mike's frequent requests for information and insistence on sorting out differences in terminology or perspective often lead to team discovery. Interaction 5 is a good example of alignment activity leading to the identification of a problem and proposal. Mike's exploitation of alignment roles extends to whole interactions. For example, Interaction 2 represents alignment in preparation for Mike's suggestion that Mike start writing the proposal. Mike's assumption of alignment roles is also in keeping with his initiation of interactions focused on project inscriptions, such as laboratory log and proposal. These external devices support discourse efforts to align and stabilize understandings between partners.

Agreement: Mike's perceptions of Dan as a knowledgeable and skilled engineer compels him to set up Dan as a model with whom to align himself, not as a peer with whom to negotiate. It is for that reason perhaps that the interactions of this team are almost devoid of disagreement. Mike is readily inclined to concede points to Dan, so long as he is privy to the information and rationale behind project decisions (with the exception of those relating to programming topics).

Cooperative Form: As noted before, the predominant cooperative form for this team is Acquiescent Co-Elaboration. Depending on the interactional focus, however, the balance point of the interaction shifts to Mike for many Project Mediation interactions and to Dan for nearly all Project Goal interactions. Interactions 5 demonstrates the difficulty Mike encounters when he attempts to act as Proposer in a Project Goal interaction, and even in Project Mediation interactions he generates little information that is new. Thus, Dan's is the voice controlling project goals and direction. Mike and Dan do not engage Co-Construction or Co-Argumentation because of their asymmetry in domain knowledge and skills. One-Sided Argumentation does not appear in the interactions because of the sensitivity of the participants to mutual alignment and agreement.

Interaction Initiation: An unexpected aspect of this team's behavior is that Mike is the initiator (Opener) of nearly every interaction. Because Mike is the less experienced member of the team, he is given the latitude to broach new topic areas as he becomes intellectually prepared for them, much as learners in Vygotsky's zone of proximal development. Dan is able to scaffold some of Mike's learning processes, but Dan, through his responses to Mike's informational needs, often finds himself in a learning process. Interactions 4 and 5 give evidence of this bidirectional learning processes.

APPLICATION STUDY 2: PARTNERS EVENLY MATCHED IN ABILITY

According to data from the Project Satisfaction Profile, both partners in the second application study registered low levels of satisfaction with their individual technical performance but high levels of satisfaction with their team communication performance. This contrast of high satisfaction with team communication and low satisfaction with individual performance could characterize a well-coordinated team tackling an unusually difficult problem or attempting to solve a problem under adverse conditions. If so, the cooperative forms and interactive behaviors of this team could well differ from those of the first application study by showing more cognitive and communicative balance.

The team partners, Greg and Sam, are males in the last year of their undergraduate programs in Electrical Engineering, and both are native speakers of English. Going into their partnership, Greg had more experience in collaborative engineering projects (7 to 12 months) than Sam (3 to 6 months). Sam, however, had slightly more experience in engineering design than Greg (3 to 6 months compared to Greg’s 1 to 2 months). Neither partner had industrial or academic experience in the technical domain of the project, which is digital signal processing (DSP), though Greg mentioned during his interview that the partners began the project with some fundamental ideas of what DSP entails. Before the project examined in this section, the partners had successfully collaborated on a project in another technical domain.

Problem Description

The design goal of this team is to implement a narrow-band (1 kHz to 3.2 kHz) spectrum analyzer. The solution requires that the team develop an algorithm to convert an input that is a time-domain signal into an output that is a frequency-domain signal and then to display both input and output signals simultaneously on an oscilloscope screen. To develop the solution, the team programs a Texas Instrument (TI) digital signal processing (DSP) chip by using software tools within the related TI workbench environment.

Interviews with Sam and Greg

As in Application Study 1, the partners gave interviews to the researcher near the conclusion of their project. The following are excerpts from those interviews.

Sam Speaks:

Our progress has been steady but slow. It's been one problem after another.

We didn't have the kind of exposure to DSP we needed to carry out this project. A lot of our time has been setting up the application environment and dealing with environment problems. So we haven't had as much time to focus on the actual DSP part.

We discovered on the first project that my strength was in hardware, and I did a lot more of the driving in that project. I think Greg, his strength is more in software, which is what we need in this project.

That's why when the TA first asked us if we wanted to do a DSP problem I was kind of indifferent about it. I knew it would be hard. I wanted to learn about it, so I said, "Well. . . ." I sent Greg an e–mail and I said if you want to do this I'm game, but I'm letting you know up front, I don't know anything about it and certainly I'm willing to do my part, but I just wanted you know up front." So Greg really made the decision to go ahead with DSP.

I wanted to learn about it if I could. I knew it would be hard. I've had people, friends who graduated with high honors, even had the class, who said they wouldn't want this project. DSP is an area that's becoming pretty popular, though. It's in a lot of demand, and I wanted to be exposed to it.

But when the TA drew the project on the board, a block diagram sort of thing, most of what he drew up there I didn't understand. I didn't know what we were supposed to do. I understood one part of it was to implement an FFT [fast Fourtier transform] *routine, and that part I understood, or at least the concept of it, but that was only one of about four or five parts of the problem. So it was not real clear what we were supposed to do. Everything we've done on this project has been research and starting from scratch.*

Greg was a little more concerned about learning the environment. That's the way we split it up, after we found out what we were doing. He would try to learn how to use the *environment, and I was going to try to learn what we were actually supposed to be doing,* [to look into] *the content of the project.*

There's never been a drop in our communication. All along in this project one of us will get frustrated and the other one will figure something out, and it just goes like that and keeps us going, I think. Back and forth.

Greg Speaks:

I feel a little better [about the project] *now than I did when I started. I can't say that I feel a lot better, but I do believe everyday we're making a little progress. It's taken more time than probably most people spend in the 464K course, but I had some extra time so I didn't really mind.*

We needed the extra time primarily because this [project] *is DSP and we didn't have the theoretical background it required. Not only that, this is a lab course, and you would typically come in having a pretty good repertoire of expertise in the theory, because the theory is what you're applying in the lab. But we didn't have that. Nor did we have a lab guide manual that most laboratories provide you to give you some direction. In fact, we had nothing, and so we had to go out and find our own manuals and do our own research and so, it was just a huge learning curve. We had a goal, it was just a long way off and we didn't know how to get there.*

So that's where the research came in, so we would know what [our goal] *was before we got there. We had a lot of sources. We had the library to go to, the World Wide Web to go to, I went to book stores. I went to several different professors. . . . . So we knew where resources were. The factor there, though, the limiting factor, was time, time to actually explore all of them. We didn't know which ones were the best, and we had to follow false leads or resources that were not really valuable to us. That takes up a lot of time.*

We did have a few things that helped us, for example, a little bit of theoretical background about frequency and modulation. And also my software background and work with different programming work benches. Sam actually has too, and he's done a little DSP programming, but just at the introductory level.

So we had a bit of a clue that we were probably going to have some challenge when you have software on a network and you've got a DOS–based system and you're operating in a Windows NT environment and trying to make all that stuff work together. And then there's having to learn all the manuals and the technical environments. I kind of had an idea of the effort that was going to be involved.

In the analysis part of the project our communication with each other was very intense. At the analysis stage you're really looking hard for a specific direction that's going to get you where you want to go, and we were trying to see if we could help each other at all.

Because I did have more software experience, I felt a little that responsibility sort of fell in my lap and you know—maybe this is not the right word—the leadership aspect of it. I try to assume a little bit of that. In the leadership role you obviously think about the bigger picture. I guess I'm a little bit keener on the operational environment and the deliverables and schedules and resources and things like that. Especially keeping in mind what the big questions are.

I think we're pretty close to being in the same situation. We're different a little bit from the historical perspective, maybe. I had a little more insight into the technical workbench environment, and he might have a little bit to add to that, I guess, but I think we're offering basically the same thing.

Implications of Interview Data

Though they were invited to speak openly about the communications with their partner, both interviewees tended to dwell on the difficulty they were having with the design problem. In fact, they showed some relief in being able to talk about it. Evidently, the difficulty stems from their lack of knowledge and experience in DSP technology rather than from any ambiguity in the problem statement itself or adverse conditions in their work environment. When the author attempted to steer the interview toward team communication styles or difficulties, the partners seemed puzzled by the drift of the question and answered in terms of the cognitive merits of their individual contributions, which they insisted were about the same in significance. Sam, for example, describes their communication as a “back and forth” effort to reach mutual understanding of the problem, and Greg likewise speaks simply of trying “to help each other.” Thus, communication itself does not seem to be problem within itself, at least in the context of the problem solving. A certain “transparency” in communication (or in the use of any other artifact for that matter) has been mentioned frequently in the theoretical literature in joint problem solving. Kuuti, for example, observes that, unless an activity becomes problematical, its character and motives are usually transparent to the participants and not accessible to conscious reflection (Kuutti, 1996). Similarly, Laver and Wenger suggest that communication may be more or less transparent when the language and understanding interact to become one learning process (Lave & Wenger, 1991). Consequently, the transparency of this team’s discourse, from the perspective of the two members, might well be an indication that their communication, considered separately from their problem solving, was effective and mutually sustained. In the nomenclature adopted in this study, one can say that their interactions were symmetrical and well aligned, which, along with agreement, is the formulation of a co-constructive working relationship.

This team’s project is the second of two such projects, both in the summer term. The other teams in this study had a long semester to solve only one design problem. As they discuss in the interviews, the duties of leadership, such as they were, shifted from one partner (Sam) for the first project to the other partner (Greg) for the second project, according to their perceptions of who had the greater knowledge in the project domain. This relationship between the possession of greater knowledge and the assumption of a leadership role is well understood by researchers and theorists (Dillenbourg et al., 1996;

Miyaki, 1986). A question in this application study, as it was in the previous application study, is whether that leadership role extends over all interactional foci, namely, Project Goal, Project Mediation, and Project Team.

Analysis of Questionnaire and Engineer Profile Data

The following subsections give analyses of the Engineering Task Preference Questionnaire results (and its associated engineer profiles) and the Project Satisfaction Questionnaire results (and its associated profiles). The last subsection discusses possible implications of the results in regard to the team's cooperative patterns.

Comparison of Engineering Task Preferences Results

Table 5-7 gives the item scores on the Engineering Task Preferences Questionnaire for the members of this team. Overall, Greg, with an item means of 2.75, shows an overall higher interest in engineering activities than does Sam, whose item means is 2.33, and this difference is significant ($t=2.06$; $df=23$; $p<.05$). His preference for managerial activities is somewhat ambivalent, because he gives a rating of 2 to Q14 and a rating of 4 to Q21, which read essentially the same: *To have (earn) the respect of my colleagues on my managerial abilities*. He gives a rating of only 2, however, for *Q11 To manage the work of others.*

From item to item, the responses of both partners trace a similar pattern, but with Greg's responses often a rank above Sam's. For example, Sam responds with a 3 for *Q4 To contribute to the business needs of the company*, and Greg gives the item a 4. Only on

TABLE 5-7
SECOND APPLICATION STUDY
ENGINEERING TASK PREFERENCES QUESTIONNAIRE RESULTS

Questionnaire Item		Sam [a]	Greg [a]	Overall Sample	
				Mean	SD
Q1	To help my company build its reputation as a first–class organization.	3.00	4.00	3.22	.7636
Q2	To work on projects that have a direct impact on the business success of the company.	3.00	4.00	3.47	.6616
Q3	To work on projects that interest me technically.	3.00	3.00	3.72	.5055
Q4	To contribute to the business needs of the company.	3.00	4.00	3.15	.7376
Q5	To work on projects that I have originated.	1.00	3.00	2.74	.8934
Q6	To explore new and innovative technologies.	2.00	3.00	3.42	.7612
Q7	To learn my job well and be able to stick to what I know.	2.00	3.00	2.95	.9032
Q8	To work with others who are outstanding in their technical achievement.	2.00	1.00	3.20	.7862
Q9	To work under capable management.	3.00	3.00	3.53	.6547
Q10	To work on projects that incorporate advanced theories in my field.	2.00	2.00	2.85	.8559
Q11	To manage the work of others.	3.00	2.00	2.54	.8905
Q12	To prepare and deliver oral presentations to upper management.	2.00	3.00	2.55	.9748
Q13	To learn how the business is set up and run.	1.00	3.00	3.11	.9177
Q14	To earn the respect of my colleagues on my managerial abilities.	3.00	2.00	2.72	.9331
Q15	To become well–known outside my company as an authority in my field.	2.00	2.00	2.69	.9823
Q16	To receive patents on my technical ideas.	2.00	1.00	2.63	1.0146
Q17	To publish articles in technical journals.	1.00	1.00	2.16	.9415
Q18	To present papers at professional societies.	1.00	1.00	2.08	.9508
Q19	To be evaluated only on my technical competency.	2.00	3.00	2.23	.9193
Q20	To have the respect of my colleagues on my technical abilities.	3.00	3.00	3.34	.7183
Q21	To have the respect of my colleagues on my managerial ability.	3.00	4.00	3.04	.8706
Q22	To have the required command of English to present myself and my ideas well.	3.00	4.00	3.63	.6577
Q23	To work where requirements are clear.	4.00	3.00	3.17	.8228
Q24	To eventually start my own business.	2.00	4.00	2.58	.9622

[a] 4 = Very important; 1 = Not important at all.

three items do the partners' responses diverge by two points: *Q5 To work on projects that I have originated* (S: 1; G: 3), *Q13 To learn how the business is set up and run* (S: 1; G: 3), *Q24 To eventually start my own business* (S: 2; G: 4). These differences reveal a general propensity of Greg to take a more adventurous approach to engineering or of Sam tobe more cautious. Neither partner has much interest in activities that mark a mature engineering career, for example, *Q18 To present papers at professional conferences* (Sam: 1; Greg: 1).

Comparison of Engineering Task Preferences Engineer Profiles

Table 5-8 gives the Task Preferences Profiles for Sam and Greg (as well as the Project Satisfaction Profiles to be discussed later). As shown in the table, Greg has a positive attitude toward Management-Corporate activities in general, while Sam gives only a neutral response to those activities. The difference is significant ($t=2.39$; $df=10$; $p<.05$). Relative to the sample means, the aggregate Microtechnical scores for both partners are low, with Sam's score of 2.00 indicating low regard for activities requiring detailed technical work and Greg's 2.50 indicating at best indifference toward such activities. Both partners record the same low score for Higher Professional activities (1.83), which indicates that these partners are even less interested in activities related to the advancement of their future professions than is the average participant from the overall sample. In fact, of the profile scores for both partners, only Greg's score in the Management-Corporate category is higher than the sample means.

TABLE 5-8
SECOND APPLICATION STUDY
ENGINEER PROFILES

Appl. Study Team	Profiles	k Preferences Profile [a]			Project Satisfaction Profile [b]							
		Mgmt Corp	Mi-cro–Tech	Hi–Pro	Team Com m	Ind Tech	Team Tech	Comm Awr	Comm Asst	Comm Impr	Comm Conf	Partic
	Sample Means	*3.05*	*3.15*	*2.52*	*3.27*	*3.03*	*3.04*	*2.32*	*2.13*	*3.19*	*3.13*	*3.60*
2	Sam	2.64	2.00	1.83	3.40	2.25	2.75	2.25	1.00	3.00	4.00	4.00
	Greg	3.36	2.50	1. 83	3.30	1.75	3.25	2.75	1.00	3.33	3.50	4.00

[a] 4 = Very important; 1 = Not important at all.
[b] 4 = Very satisfied; 1 = Not satisfied at all.

Comparison of Project Satisfaction Results

Table 5-9 shows the partners' scores on the Project Satisfaction Questionnaire. Both partners give high ratings (4) for most items having to do with team and individual communication, for instance, *Q31 Overall, I feel that my lab partner and I communicate smoothly and effectively* and *Q33 I have confidence in my ability to communicate as an engineer*. Conversely the partners strongly disagree with *Q27 Most of the time my partner and I have difficulty communicating* (S: 1; G: 1). The partners differ from each other, however, in the importance they place on good communication (*Q19 I feel the quality of our work has depended largely on the ability of my partner and me to communicate well* (S: 1; G: 4)). On the other hand, both partners are in moderate agreement with *Q17 I believe that my partner and I accomplish more as a team than either of us could accomplish*

TABLE 5-9
SECOND APPLICATION STUDY
PROJECT SATISFACTION QUESTIONNAIRE RESULTS

Questionnaire Item	Sam [a]	Greg [a]	Overall Sample	
			Mean	SD
Q1 I'm self–conscious about my speaking ability when my partner and I discuss engineering topics.	2.00	1.00	2.11	1.09
Q2 During our discussions, my partner and I often have to clarify an idea by drawing a sketch or diagram.	4.00	4.00	2.55	0.98
Q3 I feel I could have worked more effectively alone.	1.00	2.00	2.00	0.97
Q4 The longer we work together, the better my partner and I are able to communicate.	3.00	4.00	3.30	0.79
Q5 Because of communication difficulties with my partner, I feel I sometimes have to compromise on what I think is the best technical course of action for our project.	3.00	2.00	2.12	1.00
Q6 I usually communicate better (in English) with my fellow engineers than with my non–engineering friends and acquaintances.	2.00	3.00	2.19	0.95
Q7 My ability to express myself generally improves when my partner and I converse on a social level.	3.00	3.00	2.99	0.86
Q8 Generally, as the course continues, I find that my partner and I are gradually adjusting to each other's communication style.	3.00	3.00	3.27	0.66
Q9 I feel that I have the technical competence to do the work in our project.	2.00	2.00	3.52	0.66
Q10 When I disagree with my partner on a technical issue, I sometimes go along with his or her opinion because I'm afraid I can't express my own opinion convincingly.	1.00	2.00	1.67	0.82
Q11 I prefer to concentrate on the technical or computational details of our project rather than the large theoretical concepts.	2.00	3.00	2.42	0.91
Q12 I am often confused by my partner's spoken English.	1.00	1.00	1.54	0.86
Q13 During our work, I frequently help my lab partner phrase his or her thoughts in clear English.	1.00	1.00	2.04	1.05
Q14 Our project has offered me a real opportunity to show what I can do.	3.00	3.00	3.00	0.86
Q15 When we're meeting with our TA, I make a special effort to "talk like an engineer."	1.00	3.00	2.45	0.92
Q16 I sometimes feel that my technical knowledge is inadequate for the project I've been assigned.	4.00	4.00	2.13	0.97
Q17 I feel that my partner and I accomplish more as a team than either of us could accomplish alone.	3.00	3.00	3.30	0.87
Q18 My partner and I have similar experience and backgrounds, so that neither of us has to coach the other on technical concepts.	2.00	2.00	2.51	0.99
Q19 I feel that the quality of our work has depended largely on the ability of my partner and me to communicate well.	1.00	4.00	3.12	0.89
Q20 My partner and I seldom engage in social discourse.	2.00	2.00	2.20	1.00
Q21 I usually let my lab partner speak for our project during discussions with our teaching assistant or adviser.	3.00	3.00	2.10	0.93

[a] 4 = Very satisfied; 1 = Not satisfied at all.

Continued next page

TABLE 5-9 (CONT)
PROJECT SATISFACTION QUESTIONNAIRE RESULTS

Questionnaire Item	Sam [a]	Greg [a]	Overall Sample	
			Mean	SD
Q22 Our greatest communication challenge came at the beginning of our project, when we were trying to define our design problem.	4.00	4.00	2.94	1.03
Q23 There have been times when I felt my lab partner only pretended to understand what I was trying to say.	2.00	2.00	2.02	0.96
Q24 During our work together, I frequently help my lab partner put into words something he or she is attempting to express.	1.00	1.00	2.22	0.98
Q25 I speak much more fluently and freely when the TA is not present.	1.00	2.00	2.19	0.98
Q26 I tend to set the general direction and goals of our task and rely on my partner to supply the technical details.	1.00	3.00	1.53	0.79
Q27 Most of the time, my lab partner and I have difficulty communicating.	1.00	1.00	1.74	0.93
Q28 There are times when I only pretend to understand what my lab partner is saying.	1.00	2.00	3.60	0.64
Q29 I feel I have been able to participate fully in my team's decision–making.	4.00	4.00	1.60	0.89
Q30 I feel that at times my partner is confused by my spoken English.	3.00	1.00	3.41	0.71
Q31 Overall, I feel that my lab partner and I communicate smoothly and effectively.	4.00	4.00	2.25	0.96
Q32 Frequently, when we discuss the project with our TA, I find that I do most of the talking.	2.00	2.00	3.44	0.60
Q33 I have confidence in my abilities to communicate as an engineer.	4.00	4.00	1.62	0.83
Q34 Sometimes my partner and I give up trying to understand each other on a point and just go to another topic.	2.00	3.00	1.70	0.85
Q35 I sometimes know a better way to get a task done, but I'm unable to communicate my idea to my partner.	1.00	2.00	1.53	0.79

alone (S: 3; G: 3). Each partner seems to think the other partner does most of the speaking for the team (for example, *Q21 I usually let my lab partner speak for our project during discussions with our teaching assistant* (S: 3; G: 3). While most questionnaire scores indicate good team communication, some item scores suggest occasional difficulties, at least on Sam's part, for example, *Q30 I sometimes feel that my partner is confused by my spoken English* (S: 3; G: 1) and *Q5 Because of communication difficulties with my part-*

ner, I feel that I sometimes have to compromise on what I think is the best technical course of action for our project (S: 3; G: 2).

Both partners clearly feel that they lack sufficient knowledge for their project (for instance, *Q16 I sometimes feel that my technical knowledge is inadequate for the project I've been assigned* (S: 4; G: 4) and *Q11 I feel I have the technical competence to do the work in our project* (S: 2; G: 2)). On the other hand, they both are generally satisfied with their ability to participate in the project and assert their ideas (for example, *Q31 Overall, I feel I have been able to participate fully in my team's decision making* (S: 4; G: 4), and their communication improved over the course of the project (for example, *Q4 The longer we work together, the better my partner and I are able to communicate* (S: 3; G: 4)). Finally, Greg indicates a stronger preference for practical work in areas that he knows well rather than work in theoretical realms (*Q11 I prefer to work on the technical or computational details of our project rather than the large theoretical concepts* (S: 2; G: 3).

A striking feature of the Project Satisfaction questionnaire results is the similarity of the partners' scoring. Of 35 items, 17 items are scored the same. Only four item scores (Items 15, 19, 26, and 30) differ by two or more points. Of those items, *Q15 When we're meeting with our TA, I make a special effort to "talk like an engineer"* (S: 1; G: 3) and *Q26 I tend to set the general direction and goals of our task and rely on my partner to supply the technical details* (S: 1; G: 3) suggest that Greg may be more conscious of his use of professional discourse when speaking for the team and is more likely to engage in management types of activities. This latter indication supports Greg's comments during his interview that he involves himself in the "leadership aspect of it."

Comparison of Project Satisfaction Engineer Profiles

As shown by the aggregate scores in their Project Satisfaction Engineer Profiles (Table 5-8), the partners both rate satisfaction with Team Communication as high (S: 3.40; G: 3.30), which indicates that they share a sense that their project communication is effective. In the Individual Technical factor category, however, the partners indicate moderate to extreme dissatisfaction (S: 2.25; G: 1.75). Apparently, for the given project and their skill levels, the partners feel inadequate to the demands of the problem. In the Team Technical factor category, the partners show a disparity in scores. Sam is a little more than neutral toward team accomplishment, but Greg is quite pleased (S: 2.75; G: 3.25). They are neutral in their responses as to whether they must put any special effort into "talking like an engineer" (Communication Awareness: S: 2.25; G: 2.75); they feel no need to assist each other in expressing ideas (Communication Assistance: S: 1.0; G: 1.0): and both are confident in their own communication abilities (Communication Confidence: S: 4.00; G: 3.50). Finally, both partners are highly satisfied with their individual ability to contribute ideas and efforts to the project (Participation: S: 4.00; G: 4:00).

Implications of Questionnaire Results for Team Interactions

From the Task Preferences data, it seems plausible to think that Greg, with his comparative greater preference for Management-Corporate activities, will tend to initiate interactions, especially those with Project Mediation and Project Team foci, and he may more frequently take Team Regulation and Interaction Alignment Roles (see Figure 5–5). On the other hand, interactions may be more symmetrical when the partners are concentrating on Project Goal issues. Sam may be more prone to do, rather than talk. Because both partners score low in their interest in Microtechnical activities, they may seek a more expedient, rather than exploratory, path to a solution.

The Project Satisfaction profile data implies that Greg puts more stock in the efficacy of good communication than Sam does. This conjecture is based on the comparative scores of the first three factor categories of the Project Satisfaction Profile. Greg reports more than moderate satisfaction with Team Communication and Team Technical Accomplishment; yet, his satisfaction with his Individual Technical Accomplishment is extremely low. He may sense, therefore, that the good communication between partners has amply compensated for his and his partner's lack of knowledge in the domain. Item 19 of the Project Satisfaction questionnaire seems to support this conjecture: *Q19 I feel that the quality of our work has depended largely on the ability of my partner and me to communicate well* (S: 1: G: 4). By the same token, Sam seems to place less value on team communications as a potent mediator of project operations, for while he acknowledges that Team Communication is quite good, he is somewhat pessimistic about Team Accomplishment. In summary, it could be that Greg is more aware or impressed by what the team's communicative processes have achieved for them, while Sam is more aware or impressed by what the team's cognitive processes have failed to produce.

Since neither partner shows any technical dominance over the other and both are satisfied with team communications and their freedom to participate, both can be expected to perform substantive roles (Proposer, Explainer, Regulator, etc.) in team discourse. Thus, their interactions are likely to show a high degree of peer symmetry, good alignment, and general agreement or at least productive disagreement. Consequently, the cooperative forms to expect from this team are Co-Construction or Co-Argumentation or both, with perhaps Co-Elaboration during transitional interactions. Because of their peer status, the partners will probably be equally likely to initiate Project Goal interactions, but Greg, with his interest in Management-Corporate types of tasks, may be slightly more aggressive in Project Mediation interactions and more likely to perform Project Regulation roles. It should be supposed, however, that both team members are equally capable of taking any of the various conversational roles in most circumstances.

Analysis of Selected Team Interactions

As in the other two application studies, the following analyses focus on interactions that (1) exemplify the partners' working relationship during discussions focusing on project goals, mediational, or team matters or (2) seem critical to their overall project planning and decision making. Tables of the various definitions and codes are given at the beginning of the first application study, as follows: definitions of the Interaction Focus Categories are given in Table 5-4; definitions of the interactional roles as well as their codes are given in Table 5-5; definitions of cooperative forms, or patterns are given in Table 5-6.

Three interactions are discussed. The first illustrates the team's discourse immediately after receiving their problem description. The second follows their conversation as they gradually become aware of the difficulty of the problem and begin to doubt their ability to solve it. The third interaction illustrates the team's characteristic cooperative discourse after they begin to feel more optimistic about their project.

Interaction 1: Initial Project/Team Assessment

Before meeting with their TA, the team already knew they were to be assigned a problem in DSP. As their remarks reveal, they viewed the upcoming project with some apprehension, but also with excitement about working in a technical domain in which neither had much experience. The first meeting with their TA, however, seemed to alert them to the reality of their enterprise. It became apparent to the partners that the TA was not familiar with the software and at times was vague about the project requirements. Moreover, early in the project the TA, a nonnative speaker of English, was sometimes at a loss for the right word. For example, the following excerpt is a typical exchange between the team and their TA. (In all excerpts from the transcripts, S is Sam, G is Greg, and TA is the teaching assistant.)

TA: I'm not quite sure now, but actually at first I am thinking about this project, I thought that maybe anti-aliasing filter is needed, but I'm not quite sure now. I mean–
G: We may not need it?
TA: Yeah, yeah, you don't. I'm not sure now, but you don't have implement this because this is the______, you know, this is the_______.
G: Uh-huh?

The first interactional set, analyzed below, came shortly after that exchange. The interactions show the team's steady decline from cautious optimism to outright panic.

Interaction 1 Assessing the Problem
(482–581)

S: Well, what do you think? *[Open/Req-O/Mon-A]*

G: Well, uh, I guess I understand a little bit more *[Ev-S]*, but it, it's uh, I mean at this point I still think we're really in the dark *[Ev-Te]*. How do you feel? *[Req-O/Mon-A]*

S: Same way *[Ev-S].*

G: Okay *[Res].*

S: I don't, I don't know. I mean I understand, I understand the For–, the fast Fourier transform *[Ev-S]*, and I knew there was stuff, algorithms available for that *[Ev-S]*. I still don't understand exactly what we're supposed to do with it *[Ev-S]*. And so, I guess at this point we need to just do some research and figure– *[Reg]*

G: –Yeah *[Res+].*

S: –out what our questions really are *[Reg].*

G: Yeah exactly *[Res+].* It's a lot of just figuring out what our questions are *[Rpet-P]*, but we got a little bit of an idea *[Ev-R/Ev-Te]*. I'm just happy to know that this is, this kind of represents a set of events *[Ev-Ta].* At least that's a start of the, of the process *[Ev-Ta].* You know, kind of like a three-stage process *[Ev-Ta]*.

S: Well, I'm going to go get on one of those computers and see– *[Reg]*

G: Yeah, and I'm going to follow you over there *[Reg]*

Interactional Focus: The partners are comparing their initial understandings of the project instructions. The central focus is Project Team, that is, their current status as a project-solving entity.

Interactional Roles and and Cooperative Patterns: Overall, the partners are aligning themselves with each other and with the needs of the project, as they understand it so far. Consequently, the interactional roles are those by which they disclose and evaluate their applicable knowledge and define the task itself. The roles for each partner are as follows:

Sam: Opener, Requestor-Opinion, Monitor-Alignment, Evaluator-Self, Regulator, Responder-Agrees

Greg: Evaluator-Self, Evaluator-Team, Requestor-Opinion, Monitor-Alignment, Responder, Responder-Agrees, Repeater-Partner, Evaluator-Resource, Evaluator-Team, Evaluator-Task, Regulator

Both partners add substantively to the interaction, with Sam drawing attention to a technical component of the problem and Greg remarking on the structure of the problem itself. Consequently the interaction is symmetrical. They carefully monitor their mutual alignment (which, after all, is what the interaction is about), and they obviously agree throughout. The cooperative form, therefore, is Co-Construction.

Discussion: The team's work together depends on their construction of a common ground of of understanding (Clark & Brennan, 1991; Clark & Schaefer, 1987), and a part of that common ground is shared knowledge of the team's capacity to understand and solve the assigned problem. In effect, the team itself is a resource, one with properties and limitations that must be understood before they can move on. Thus, in this interaction, the team members are assessing their individual and collective status as problem solvers. Note that both partners are relaxed in their self-disclosures and that they are obviously attempting to assure each other of their like-mindedness or give emphasis to whatever they think will be of benefit to the both of them. The exchange is efficient, with each speaker responding briskly to the other with the information expected. Thus, they start the project by pooling their knowledge of the project and their understanding of the instructions, a promising way to begin.

Already in this early interaction a dichotomy in the partners' approach to the problem begins to appear. Sam's contribution focuses on a discrete technical component of the problem (Lines 6-8), while Greg's contribution focuses on the linear structure of the problem-solving procedure (Lines 13-15). This evidence for a difference in perspective is supported by the interview data and the Task Preferences Profile, both of which indicate that Greg is more inclined to keep the larger picture in mind as the project proceeds. The different perspectives, however, are highly complementary: Greg's bears on establishing the structure of the task and Sam's bears on fleshing out that structure with details. Both partners, however, seem to be action oriented and waste no time in getting to a computer and beginning work (Lines 16-17).

Interaction 2 Initial Session at the Computer

In Interaction 2, the team is involved in three complex processes simultaneously: to define what the problem requires (Project Goal), to define what their resources are (Project Mediation), and to evalutate themselves as a problem-solving entity (Project Team). Their difficulty arises because one domain largely defines the other, yet none contains signposts as to what is meaningful. They are working in an informational vacuum. They neither have confidence in their current information sources nor do they know where else to look. Consequently, they find themselves sitting in front of a computer looking incomprehensibly at screen images. It is interesting to compare this team's efforts with the generic design activities described by Goel and Pirolli in Appendix A.

The interaction takes place during a lengthy session at the computer. The partners are working together, with Sam at the keyboard (thereby controlling the mouse) and Greg sitting by, looking on and commenting. The topic of the interaction is generally "what are we seeing and what can we make of it?" This interaction is given in some length because it captures the team's succession of confusion, frustration, and even panic as appraise the problem.

Interaction 2 [At the computer. Sam is at the keyboard, with Greg looking on.]

G: Let's see. We're at the uh–*[PI]*

S: –TI [Texas Instruments] software *[Rprt]*.

G: –lab workbench, going on the computer now *[Rept]*. We've got it logged on *[Rept]*. We're going into TI software *[Rprt]*. C th– *[Unc]*. How are, why are you selecting C3X2? *[Req-I]*

S: Because I don't know what else to select *[Just]*.

G: Oh, you're selecting anything *[Expli-P]*. Oh, wait I think, that EVM, EVM in the middle one *[Pres]*.

S: This is, uh– *[PI]*

G: Here it says EVM Setup *[Pres]*.

S: This is a display of the register to something *[Pres]*.

G: Okay *[Res+].* EVM30 *[Pres]*.

[Pause (30 seconds) while Sam opens and closes various windows on the computer.]

G: All right, that means absolutely nothing to me *[Ev-S]*. I have no idea what that is *[Ev-S]*. Blow up that screen with the–. Yeah. *[Reg]*

S: Well? *[Req-O]*

G: It doesn't help *[Ev-Re]*.

S: They're showing– .*[PI]* This is memory *[Pres]*. This is CQ registers. *[Pres]*

G: This is some type of this, uh, assembly code compiler thing, or. . . .*[Pres]*

[Pause (30 seconds) as both speakers examine succession of screen images. Tapping at the keyboard.]

G: Is there a Help screen? *[Req-I]* Is there a Help feature up there that we can– *[PII]*

S: I don't see one. *[Res-]*

G: –generate documentation? *[Req-I]*

S: *[Inaudible. Reads off the screen under his breath.]*

[Pause (30 seconds). More tapping at the keyboard.]

G: Holy moley *[Unc]*. How do we get out of this, this class? *[Reg/Req-I]*

S: Hunh-heh, there's not going to be any getting out *[Reg]*.

[Short pause. More random explorations at the keyboard.]

S: I mean, I mean I don't really know where to start *[Ev-S]*. I don't know what we're supposed to do *[Ev-S].*

G: I'm going to try to get his attention and see if he can discuss what this is *[Reg].*

[The team meets briefly and inconclusively with the TA. Greg checks out a book from the Parts Bin. The interaction resumes.]

G: All right, Sam, I got a [book] on it *[Rept].* They only have one related to our stuff *[Ev-R],* and the downside is that we can't check this out overnight *[Mon-S].* So any time we want to reference this, we got to go borrow it, or just for the day check it out while we're in the lab *[Mon-S].*

.
.
.

S: Well, my thinking is, uh, we just jump in with both feet and learn by doing *[Prop/Reg]*. I learn a lot better by doing than– *[PI]*

G: –experimenting around *[Expli-P].* You want to go try and get a function generator hooked up and play with this a little bit? *[Req-O]*.

S: Well– *[Unc]*

G: Or do we have to? *[Req-O].*

S See, I don't– I mean I was just trying to play with this a little bit *[Rprt]*.

G: And I assume it's– *[PI]*

[Both partners are looking at the book and commenting on its contents.]

S The EVM, I think, is the actual physical board *[Pres/Expla].* I think this SIM 3XW is like a simulator *[Pres/Expla]*. (Pause) Uh, all right, well here it talks– *[PI]*

C Implementation on FFT *[Pres]*. So that's that part of it *[Pres]*. Um, starting on page 53, *u*h, anti-aliasing *[Pres].* I don't know *[Ev-R]*. Uh, this other thing [inaudible] adaptive filters *[Pres]*. Here's some filters *[Pres]*. Infiltration. *[Pres]*. So perhaps this book will have part of what we need *[Ev-R]*.

S: Well, maybe we just need to read this– *[PI]*

G: But, yeah *[Res+]*.

S: –overview and find out– *[Reg]*

G: –I'd like to extend the authorization of it first, yeah *[Reg/Mon-S]*.

S: Yeah. I'd like to *[Res+]*. I just don't really know how to use this software at all *[Ev-S]*. Uh. that's the only version? *[Req-I]*

G: We've only got one copy *[Ev-R]*.

S: I mean I think we need to just learn how to maybe, just learn how, how it works and maybe put a very basic program– *[Prop/Reg]*

G: –Yeah *[Res+]*.

S: –one that really does nothing, just– *[El-S]*

G: –Yeah *[Res+]*.

S: –just compile and run *[El-S]*.

G: Yeah, yeah, exactly *[Res+]*. That's what I want to do *[Res+]*. I just want to understand the overall– *[PI]*

S: –maybe structure– *[El-S]*

G: –of how we're suppose to use this *[Reg]*.

S: Maybe change some file or something on the memory *[El-S]*.

G: Uh-huh, exactly *[Res+]*.

[Pause, 30 seconds]

G: But, we really need someone to at least show us how, for the first time, how to do something *[Prop/Reg]*. Otherwise, it's going to take, you know, we could be here a week trying to figure out how to use this thing *[El-S]*.

[Pause, 30 seconds]

G: I'm going to ask if there's any way we can get a demonstration of this *[Reg]*.

S: He [the TA] doesn't, he said he didn't know this software *[Ev-R]*.

G: Yeah, but he might know somebody else who could, maybe one of the other students that– *[Ev-R]*

[Pause, 10 seconds]

G: I mean unless you’re, I mean– *[PI]*
S: Nah, I’m not getting an inferiority complex *[Ev-S]*.
G: Well, what, uh, what I mean is what would, what could we do right now if we, I mean is there any chance that we could, I mean, I just kind of bring this up, you know, a crazy idea, is there any chance that we could go talk to, uh, the professor of this class about changing our area? *[Prop/Reg/Req-O]* What do you call this, this area? *[Req-I]*
S: DSP *[Expla]*.
G: I mean what do they call it as a technical area in the 464 program? *[Req-I]*
S: We could find [the Head TA] and ask him would probably be the place to start *[Reg]*.
G: Um, yeah, I mean– *[PI]*
S: Well, nobody would really understand this problem *[Ev-Ta]*.
G: I guess I’m asking you, is– *[Expli-S/Mon-A]*
S: Yeah, I’m game *[Res+]*.
G: Are you game for something that radical, as just starting over? *[Req-O/Mon-A]*
S: Yeah *[Res+]*.
G: I am too *[Res+/Mon-A]*.
S: I mean because he doesn’t know the software; he doesn’t know like how to explain it *[Ev-R]*.
G: We can’t take the manual home, yeah *[Ev-R]*. That’s kind of a radical idea, but maybe *[PI]*
S: Let’s go talk to Fred [Chief Teaching Assistant] *[Impl]*
G: Think we can find him? *[Req-O]*
S: Yeah *[Res+]*.

Interactional Focus: This interaction focuses on the operation of software that is essential to the team’s project. The primary focus, therefore, is Project Goal. Throughout the interaction, however, the partners are also identifying and evaluating their sources of information and their individual understandings. Consequently, as mentioned before, the interaction contains elements of all three interactional foci: Project Goal (What defines a solution?), but also Project Mediation (How do we get to that solution?) and Project Team (Are we capable of a solution?).

Interactional Roles and Cooperative Forms: The team is examining software they will use to carry out their project. Sam, who is controlling the mouse, has more command of what the team sees on the computer screen, so that Greg takes a more responsive role at first, as in Line 4 when he asks “Why are you selecting C3X2?” and Sam replies “Because I don't know what else to select." They both (as Presenters) identify a few items on the screen in Lines 6-10 and Lines 19-20, but generally they understand little of what they see. Greg (Evaluator-Self, Line 14) is the first to confess his ignorance. In Line 25, he (Requestor-Information) asks whether there is a Help function for generating documentation. Finally, in Line 32 Greg expresses his alarm at the problem's intractability, and he, perhaps facetiously at this point, suggests the possibility of dropping the course.

Sam (Evaluator-Self), after exploring a number of commands on the computer, voices his own frustration (Line 36), which leads Greg, in Line 38, to suggest that they seek guidance from the TA (who, after a brief discussion, refers them to a text). Greg returns to the work station with the text (Line 43). Sam (Proposer/Regulator) proposes that they just need to "jump in with both feet" and learn the project by doing, and not by reading about it (Lines 50-51). Nevertheless, for a few turns the partners thumb through the pages and (as Presenters) point out to each other descriptions of components that seem applicable to the problem (Lines 61-66). Though the text gives them a few elementary ideas, it does not help them understand software operations. Sam proposes (Proposer/Regulator) that they learn the system by running a simple program as an exercise (Lines 74-85), and Greg agrees. Greg, however, is also aware that they cannot run the program without knowing more about it, and, as Regulator, he suggests they find someone to demonstrate program (Lines 89-95). Before he goes, however, as Proposer/Regulator, he tentatively raises the question of whether the problem is too much for the team, and if so, perhaps the team could get permission to work on another problem

(Lines 104-107). Both partners point out reasons for discontinuing the project and seeking another, and they agree on discussing the possibility with the head TA.

Both partners exercise a wide range of roles in the interaction:

Sam: Reporter, Justifier, Presenter, Explainer, Requestor-Opinion, Responder-Disagrees, Regulator, Evaluator-Self, Proposer, Elaborator-Self, Evaluator-Resource, Explainer, Evaluator-Task, Implementer

Greg: Reporter, Requestor-Information, Explicitator-Partner, Presenter, Evaluator-Self, Regulator, Evaluator-Resource, Responder-Agrees, Proposer, Elaborator-Self, Monitor-Standards, Explicator-Partner, Requester-Opinion, Monitor-Alignment

The range of substantive roles played by both partners suggests that they are balanced in their contributions to the interaction. Besides symmetry, agreement is clearly evident throughout the interaction. Alignment is present in the strict sense that they both know what the other is saying (but see the discussion below). Overall, therefore, the cooperative form that predominates in this interaction is Co-Construction.

Discussion: Though the partners are aligned in their understanding, there is evidence that the two partners are looking at their situation from different perspectives. These perspectives relate to the approach they should take to gaining an understanding of how the software works. Greg, for example, indicates early that he is willing to consider dropping the project for another that is not so foreign to the team's experience and knowledge (Line

32). He is also quick to realize that the team may not be able to solve the problem unless they get outside help. In Line 38 he consults with the TA; in Line 43 he brings in a text he has checked out; and in Lines 89 he suggests they find some person to demonstrate the software. Sam, in contrast, seems more inclined to see the problem as a self-contained challenge that will yield its solution to brute mental force. In Line 50, he talks about jumping in with both feet and learning by doing. In Line 74, he says that they should learn how the software works by running a simple program. Sam, it seems, is more focused on the character of the problem itself and places his faith on the application of sheer cognitive effort, while Greg is more focused on the range of resources that can be found to guide them to the solution.

Again, these two perspectives are not mutually exclusive or contradictory. One partner is simply thinking generally along a cognitive track and the other is thinking generally along an informational or mediational track, but not at all the exclusion of the other. Their contributions are decidedly other-directed. Moreover, the difference in perspective may be partly or wholly because of Sam's control of the keyboard: his remarks derive from what he sees on the screen immediately in front of him, while Greg looks at the screen intermittently. On the other hand, the Engineering Task Preferences Profile suggests that Greg (with a score of 3.36 in Management-Corporation activities) is much more inclined than Sam (with a score of 2.64) to engage in activities that improve the problem-solving conditions of the team. One of those conditions is the availability of information. For that reason, Greg may be expected to take the broader view of the project, identify resources, and generally take on tasks that help the team function. Researchers like Rogoff have observed the importance of differences in perspective in the ability of collaborators to make progress in their interactions (Rogoff, 1990). In this case, such differences do not lead to cognitive conflict; rather they are mutually constraining views that guide the partner's thinking along productive channels. One partner's contribution stimulates the other partner's contributions, but within the bounds of the common ground they are both laying (Clark & Schaefer, 1987).

In any case, the two perspectives converge when Greg decides that the information to solve the problem may not be forthcoming in time to finish the project and when Sam decides that "Nobody would really understand this problem" (Line 112). Consequently, they agree to "reverse the transformation function" (Goel & Pirolli, 1989), that is, change the problem to suit their circumstances.

Interaction 3 Example of Working Interaction

The team's attempt to be assigned a different problem was not successful. Both a faculty member and the Chief TA restored their confidence that they could handle the problem and pointed them to good informational sources. When the team returned to the laboratory, they commented as follows:

S: Well, it didn't sound like there's really any getting out of this one, so–
G: –I guess so.
S: –we might as well just get it done.
G: Yeah.
S: Well, we'll do what we can.
G: So, and I think that TA understands that we're new at this, and I just asked him a thing or two before you got there, if we could just use examples as opposed to trying to learn everything from new, and just, you know, make some minor modifications, you know, existing code as opposed to building everything from scratch.
S: Yeah, because we're new to this application. There's no way we can learn three or four semesters of stuff in one, in three weeks, so–

G –Yeah.

The following interaction,which takes place not long after the above interchange, is an example of this team's normal communication style. Again they are the computer, and Sam is at the keyboard, and Greg, with a manual, is looking on. Note that in some lines the partners are finishing each other's sentences. The partners speak in rapid succession.

(1891 –1981)
G: All right, so these are the files *[Pres]*.
S: File.bat *[Expli-P]*.
G: File.bat *[Rept-P]*.
S: Um, but it just tries to run this from [word] basically, just AC30 *[Expla]*, but this is the extension here *[Expla]*. We haven't been using that *[Reg]*.
G: Okay, okay *[Res+]*.
S: Uh, that's commented out *[Pres]*, and that's commented out *[Pres]*, so there's basically just the main basic C program *[Expla]*.
G: Okay *[Res+]*. That's test C, right? *[Expli-P]*
S: Yeah *[Res+]*. Uh, change path *[El-S/Pres]*. That's all it runs *[Expla]*. It changes the path to include the working directory *[Expla]*. The system 32 and in TDL2 is what the original directories were *[Expla]*, so I've just deleted those *[Reg]*.
G: Okay *[Res+]*.
S: -in C10 *[Expla]*.
G: Okay *[Res+]*.
S: It should include all those four *[Expla]*. I think there's still something going on that we didn't realize– *[PI]*
G: –Like there's four? *[Req-I/Rept-P]*
S: –in this directory *[Anal]*.
G: Wait *[Reg]*. TI *[Pres/Expli-P]*.
S: B *[Pres/Expli-S]*
G: D *[Pres/Expli-P]*
S: There's the first one *[Pres/Expli-S]* There's the second one *[Pres/Expli-S]*.
G: Second one *[Pres/Rept-P]*.
S: There's the third– *[Pres/Expli-S]*
G: Oh, there's the third and the fourth *[Pres/Rept-P/Expli-P]*. All right *[Res+]*.
S: Okay, okay *[Res+]* Uh, test dot C and B *[Pres]*.
G: So, in order to run that change dot, or change in a store path, you just type change in a store path *[Reg]*. Right? *[Req-Cf]*
S: Right *[Res+]*
G: And dot bat is an executable file *[Expla/Req-Cf]*.
S: Right *[Res+]*.
.
.
.
G: I don't know what that is *[Ev-S]*. Oh, that must be an output file from something *[Expla]*.
S: I think it is *[Res+]*.
G: Or it's– *[PI]*
S: It was created today *[Expla]*.

G: You didn't write anything that's 5,000 bytes *[Reg]*, so it must be an output from some process *[Expla]*. It's probably an output from one of those, yeah *[PI]*.
S: It's the output from when we– *[PI]*
G: –compiled *[Expla]*, yeah *[Res+]*.
S: –compiled that other *[Expla]*.
G: Yeah *[Res+]*. Let's delete it *[Reg]*, or, uh, can you, can you purge it? *[Req-I]*
S: Yeah, I can do it *[Res+]*.
G: Okay, run the bat *[Reg]*.
S: Run.bat *[Rept-P]*. Is that–? *[PI]* So instead of typing that line every time, just type [word] *[Expli-P]*
G: Uh-huh *[Res+]*.
S: The object file and the assembly file are outputs of when we compiled the test program by running it *[Expla]*.
G: Okay, so really the only thing we're going to see– *[PI]*
S: –is this *[Pres]*.
G: Run.bat is the one we really want to use *[Reg]* because the other one's the old one *[Ev-R]*.
S: Yeah *[Res+]. T*his dot dash O *[Pres}* I'm almost certain is, creates an object file or removes an object file *[Expla]*.
G: Yeah, that's what this says next page *[Pres/El-P/Ev-R]*.
S: I'm not sure what the Z and the dash – *[Ev-S]*
G: It says here– *[PI]*
S: (inaudible)
G: –Z is to invoke the linker option *[Pres]*. Uh, O is to invoke the optimization option, the opt file *[Pres]*. Uh, okay, good enough *[Ev-Ta]*.
S: Well, I guess I'll have to tell my wife "Nice knowing you. See you in another four weeks" *[Dig]*

Interactional Focus: The team is attempting to understand the command functions of the software they will use in solving the design problem. Learning the operation of the software is an essential subgoal on the critical path to a solution. The interactional focus, therefore, is Project Goal, with overtones of Project Mediation.

Interactional Roles and Cooperative Forms: The partners are viewing information on the computer screen and making assumptions about what they see. For this reason, both partners adopt the roles Presenter and Explainer quite frequently, and they are working in tandem with each other. The interaction begins when both partners recognize important files with the suffix .bat (which are batch files). Thus they firmly establish that they are both addressing the same topic, with Sam explicating Greg in Line 2 and Greg repeating Sam in Line 3.

Sam, who has been experimenting with the software, points out (as Presenter and Explainer) several changes on the screen and identifies for Greg the location of the C program. In Lines 18-27, Greg, following the explanation closely and adding to it from his own understanding, has Sam make explicit the four files remaining in the directory. Greg (Regulator) then verifies the procedure for running a change in a store path, which Sam confirms (Lines 28-30), Next Greg {Explainer and Requestor-Confirmation) identifies the .bat as an executable file. The turn taking is rapid. Greg is pointing and orienting himself to the screen contents, making comments, requesting information, and seeking seeking confirmation. Sam is doing likewise, and their respective roles are nearly the same. In Lines 36-46, Greg (Evaluator-Self) indicates a file he cannot identify, but the partners converge simultaneously on the realization that it is an output file from a previous process. After deleting the file, Greg (Regulator) has Sam run the .bat executable (Line 47). Sam repeats the request, and this time the repetition represents an acknowledgement that he heard the request and a confirmation that he is carrying it out. In Lines 50-51, Sam (Explainer) identifies an object file and assembly file as outputs from a previous compilation. Sam and Greg then observe the results of the .bat executable and seem content in learning that run.bat is the executable they will be using (Lines 57-61). The partners then determine the functions of other executables on the screen (Lines 60-66). Greg (Presenter) consults a book for their definitions and, as Evaluator he expresses his satisfaction with the task so far. Sam (Digressor), aware that they are on the right track but sensing they have a long way to go, complains in good humor.

The summary of interactional roles is as follows:

Sam: Explicitator-Partner, Explainer, Regulator, Presenter, Responder-Agrees, Elaborator-Self, Analyzer, Explicitator-Self, Repeater-Partner, Evaluator-Self, Digressor

Greg: Presenter, Repeater-Partner, Responder-Agrees, Explicitor-Partner, Requestor-Information, Regulator, Request-Confirmation, Explainer, Evaluator-Resource, Elaborator-Partner, Evaluate-Task

The partners are well matched in the productive roles they play. The interaction, therefore, shows a great deal of symmetry. There is little confusion, and they expend little effort trying to understand each other. The turns are short, spontaneous, and in rapid sequence, and the ideas of what partner spring from the ideas from the other partner. The partners are quick on the uptake, to the extent that their turns sometimes overlap with the same thought, a sure sign that they are well aligned. In short, as the partners explore the various screen objects, they reach understandings together. The interaction is symmetrical and the partners are aligned and in agreement, the interaction is an example of Co-Construction.

Discussion: The partners anchor this interaction on the topic of the .bat files, or batch files (Lines 1-3). Greg points to them on the screen, Sam expresses what they are, and Greg repeats. Barron states that such repetitions are common in close problem-solving discourse for a number of reasons {Barron, 2000 #68}. For example, the partners may be confirming that they heard correctly or they are giving emphasis to an idea. In this case, because of the many features on the screen, they are perhaps assuring each other that they are focused on the same objects.

The partners are speaking in rapid succession. Turns are short, to the point, but informative, even though some of what they say is guesswork. While they may be unsure about the information they see on the screen, their own turns do not confuse each other. They in fact seem to be working within a mutually sustained problem space.

In Line 16, Sam mentions that there should be four files in a directory, and in Lines 20-26 Greg has Sam point out all four. At this early point, when the team is trying to identify the command lines in a compiler program, any single item of information may have unexpected significance. Greg's insistence that he know the identify of all four files ensures that he knows what Sam knows. This repetition and request for explication ensures that the partners keep abreast of each other and effectively helps maintain a shared reference. At the same time, both are thinking independently, but without contradiction. For example, in Lines 36-45, they both attack the problem of identifying a file. Their thinking converges on the same answer almost simultaneously: it is the output from when code they ran earlier. Their overlap when saying the word "compiled" (Lines 43-44) is typical of this team. Frequently they finish each other's sentences or reach identical ideas simultaneously (even though they are thinking along slightly different channels, as discussed above). Roschelle and other researchers refer to such turns as “collaborative completions” (Roschelle & Teasley, 1991) also see (Lerner, 1987; Wilkes-Gibb, 1986), or “socially distributed productions.” As Roscelle says, such occurrences may be “a particularly effective means for constructing shared knowledge because it spreads the interrelated goals, features, and actions of a knowledge element across conversational turns. This provides multiple opportunities for partners to contribute to the construction and verification of the new piece of knowledge” (p. 77).

During this interaction, Greg is alternately looking at what appears on the screen and at what is contained in a book about the compiler command extensions. Once again, Greg seems to serve as a project “informator” (Zuboff, 1988), while Sam at his position at the keyboard is more of an executor. At the end of the interaction, the team seems to feel some relief that they have at identified at least a few fundamentals about the software, but they also realize they have little understanding as yet of how to put the software to use in building a spectrum analyzer.

Conclusion of Application Study 2

Barron defines mutuality as “the extent to which there is reciprocity and balance in interaction such that there is potential of all members to contribute and to be heard” (Barron, 2000) p. 16. The interactions of Sam and Greg seem to exemplify that mutuality. Their conversations are efficient; that is, they move rapidly and transactively while bearing a great deal of information, as the partners piece together what they do know and bracket off what they do not know. Alignment seems to be a effortless part of their communications, to the extent in fact that in their interviews they could barely conceive of communication as a feature of their collaborative thinking. Many of their interactions demonstrate the cooperative form Co-Construction, that is, a form of purposeful dialogue that researchers associate with positive collaborative outcomes (Azmitia & Montgomery, 1993; Barron, 2000). This team was a case in point, because, despite the obvious difficulty they had understanding the problem early in the project, in the end both partners' project grades were in the top percentile, best of the participants in this study.

APPLICATION STUDY 3 TEAM WITH STRONG PARTNER DIFFERENCES IN MOST PROJECT SATISFACTION FACTORS

The analysis of this team will make use of a simplified version of the framework developed in this study. The previous application studies included analyses of the interview data and the line items of the questionnaire instruments, as well as data from the profiles and interactions. In large-scale studies or classroom situations, interviews with individual team members may not be practical. In addition, the profiles are consolidations of data from the questionnaires. A parsimonious use of the framework, therefore, would limit the analysis to data from the profiles and the interactions alone, and that approach will be tested in this section.

This team was selected for study because its partners, Yass and Jack, showed sharp differences in their Project Satisfaction Profiles. Those differences suggest that neither partner found the project a satisfactory experience, but for different reasons. As a result, the cooperative forms appearing in this team's interactions can be expected to differ from those of the other application study teams, who generally regarded their projects positively. Yass is female, a senior, a nonnative speaker of English (native language is Bengali), and she has been in the U.S. for 3 years. She ranks her reading and writing skills in English as excellent and her listening and speaking skills as good. Jack is male, also a senior, and he is a native U.S. citizen. Both partners have had 3 to 6 months experience collaborating with engineers and 7 to 12 months experience in design work.

Problem Description

The team's project was to build software-based X-10 receivers. The X-10 communication protocol is used for remote control of home electrical appliances. The control system uses the ordinary AC wiring system of the household to communicate with the appliances. The X-10 was created at a time before the proliferation of personal computers (PCs) and does not allow for the kind of exact control that most users would like from a computer interface. This project, therefore, is an attempt to build a software-based X-10 receiver and add extensions to the protocol so that PC-based control can be easier to use.

Comparison of Task Preference Profile Data

The Task Preference Profile for this team is given in Table 5-10. Both partners show only slight interest in performing Management-Corporation activities (Yass: 2.55; J: 2.45). These relatively low scores for both partners suggest that there may be a lack of project management and regulatory roles in this team's operations; that is, neither partner

TABLE 5-10
ENGINEER PROFILES: APPLICATION STUDY 3

Appl.-Study Teams	Profiles	Task Preferences Profile			Project Satisfaction Profile							
		Mgmt Corp	Mi-cro-Tech	Hi-Pro	Team Com	Ind-Tech	Team-Tech	Com Awr	Com Asst	Com Impr	Com Conf	Partic
	Sample Profile	*3.05*	*3.15*	*2.52*	*3.27*	*3.03*	*3.04*	*2.32*	*2.13*	*3.19*	*3.13*	*3.60*
3	Yass	2.55	3.17	2.00	1.70	2.50	2.75	2.75	1.00	3.33	3.50	4.00
	John	2.45	2.67	1.50	3.20	4.00	1.25	2.00	2.50	2.00	4.00	1.00

may supply the types of behaviors that foster mutuality and shared reference—behaviors that tend to improve the problem-solving capacity of the team as a unit.

Another difference lies in the partners' preferences for Microtechnical activities. Yass has a more positive attitude toward the more detailed and cognitive aspects of engineering tasks, but Jack is fairly neutral in this factor. This difference suggests that Yass may be more inclined to supply or attend to the technical details of the project. Like the other participants in this study, neither partner is particularly interested in the Higher Professional engineering activities.

Overall, the Task Preference Profiles raise questions about how these two partners will manage their joint enterprise and how Yass's greater enthusiasm for technical work will manifest itself in the Project Satisfaction Profile and interactions.

Comparison of the Project Satisfaction Profile Data

The Project Satisfaction Profile (Table 5-10) indicates that this team had difficulties working together collaboratively. In Team Communication, for instance, there is a wide difference between the partners' satisfaction with their ability to communicate. Jack's score of 3:20 is the same as the sample means, which indicates a high degree of satisfaction, but Yass's score of 1.70 indicates a distinct dissatisfaction with team communication. On the surface, then, Jack seems to think they are communicating, while Yass seems to think they are not. Possible interpretations of this difference are that Jack was able to discourse upon the project with some facility and at length, while Yass could not. Yass may have lacked the technical knowledge to hold her own. Alternatively, being a nonnative speaker, she may have had difficulty comprehending Jack, articulating her project ideas, competing with Jack for dominant conversational roles, or any combination of those liabilities. In any case, a great deal would depend on the ability of the team to accommodate themselves to linguistic differences. Finally, there may gender and cultural differences at work in this team's communication practices. While the framework cannot reveal the underlying reasons for the differences in the partners' perceptions of team communication, it should be able to show how those differences relate to cooperative forms in the team interactions. At this point in the analysis, a plausible conjecture is that this team's interactions will reveal problems in one or more of the interactional dimensions: symmetry, alignment, and agreement.

The partners show another major difference in satisfaction with their Individual Technical performance, with Jack reporting a perfect 4.0 and Yass reporting a noncommittal 2.5. This difference is almost a reversal of the partners' scores in the Microtechnical category of the Task Preference Profile, where Yass recorded considerably more enthusiasm than Jack for the more technical engineering tasks. Somehow Yass's enthusiasm was checked or overridden during the actual project performance, while Jack's abilities were able to flourish despite his self-reported lack of enthusiasm for technically detailed work. An explanation may be that Jack entered the project with more prior knowledge in the project domain than Yass could offer and thus had more freedom to explore his own ideas; in that case two sets of questions arise: (1) does Jack present that knowledge in such a way to include Yass in the problem space, take advantage of her thinking, and thereby enhance the mutuality of their working relationship, and (2) does Yass manage to make a place for herself in the problem space, identify and assume responsible roles for herself, and thereby bring her own unique abilities into play. At stake is the degree of collaboration that these partners can achieve in their problem-solving discourse.

The low scores of the Team Technical Accomplishment indicate that neither partner was pleased with their efforts to mold the team into an effective problem-solving entity. Yass is precisely neutral toward the quality of the project's technical progress (Y: 2.75), and Jack registers extreme dissatisfaction with their work together (J: 1.25). An interpretation of this difference should take into account the scores on the two previous factor categories, Team Communication and Individual Technical Accomplishment. First, from Jack's point of view: Jack was perhaps able to conduct his end of team communications to his satisfaction (this conjecture is also supported by his score of 4.00 in Communication Confidence), and he was pleased with his own technical contributions to the project. Thus he is pleased with the quality of his own work, whether communicative or cognitive. Aspects of the project that pertain to teamwork, however, receive his extreme dissatisfaction. While he could "talk at" Yass and he could control the origination of project ideas, he seems to feel that he could not very well work with his partner with any degree of mutuality. In effect, he is saying that he feels he could have worked better without her.

From Yass's point of view: Yass, whose score of 2.75 in Team Technical Accomplishment shows only tepid regard for team results and is only slightly higher than her low score in the Individual Technical performance category, seems to think she has gained little from the technical aspects of the project. Quite possibly a correlative to her dissatisfaction in technical accomplishment is her low score of 1.70 in Team Communication, which is a strong indicator that she simply could not communicate with her partner and, in her view, both she and the team suffered as a result. In sum, Yass had two factors working against her simultaneously: team communications did not work in her favor (possibly for linguistic reasons, possibly because of her partner's style of presenting information) and her individual technical abilities were somehow thwarted (possibly because her partner aggressively wielded a greater amount of ready knowledge in the domain).

Consequently, Jack can be seen as taking roles that supply new conceptual information to the project (roles such as Proposer, Explainer, and Elaborator) and Yass, to hold her own, can be seen as responding or at best critiquing ideas in the flow of Jack's discourse. What seems to missing in this team is any mutual monitoring and team regulatory process that might bridge the differences between these two partners and help them establish a healthy, co-productive alignment.

Neither partner is especially aware that he or she attempts to tailor their language to conform to ideals of professional discourse, although Yass is slightly more than neutral in that regard (Communication Awareness: Y: 2.75; J: 2.00). Jack occasionally assists Yass in expressing an idea, while Yass never gives Jack that assistance (Communication Assistance: Y: 1.00; J: 2.50). From Yass's perspective, communication with her partner improved significantly as the project continued beyond the definitional and planning stage; from Jack's perspective, communication difficulties persisted (Communication Improvement: Y: 3.33; J: 2.00).

The last two Project Satisfaction factor categories, Communication Confidence and Participation, provide additional insights into how these partners may work together. Though Yass is a nonnative English speaker, her confidence in her ability to communicate is almost as high as Jack's (Y: 3.50; J: 4.00). Yass's score in this category indicates that, in her view, at least some of any dysfunctionality in this team's cooperative efforts must be attributed to conflicts other than those based on linguistic differences. Again, underlying causes of incompatibility may be differences in such variables as technical background, gender or ethnic factors, motivation, and interactions among those factors.

The partners' scores in the Participation category are difficult to interpret. This category represents the participants' answers to a single question: *Q29 I feel I have been able to participate fully in my team's decision making.* The participants' scores for this item (Y: 4.00; J: 1:00) seem to contradict their other responses in the Project Satisfaction

Profile. On the other hand, these responses may reflect the partners' different perceptions of the team experience. Jack envisions what he could have accomplished had he worked alone. Yass, more dependent on Jack's expertise, its pleased with what she was able to contribute.

Summary of Profile Data

The Task Preference Profile indicates that neither partner is particularly interested in performing activities that regulate or organize team operations or create optimal conditions for team problem solving. Yass shows an average interest in performing tasks that require technical ability and skills, but Jack is fairly neutral toward technically-involved tasks. Neither are interested in activity that would advance their careers in any public way.

The Project Satisfaction Profile indicates clearly that this team may have failed to work out a collaborative relationship. Yass indicates her extreme dissatisfaction with team communications, and at least one source of that dissatisfaction may be her English. Jack is extremely satisfied with his own technical contribution to the project, but extremely dissatisfied with what the team has accomplished, and this difference indicates that he felt handicapped by working with his partner. Yass is neither pleased nor displeased with her own technical accomplishment and is only slightly satisfied with the accomplishment of the team. Communicative Awareness is not an issue of either partner, and Jack reports that at times he must help Yass frame her thoughts, but not particularly often. Yass feels that communication improved over time; Jack felt they became worse.

In apparent contradiction to all else, Yass feels strongly that she was free to participate in the decision making, while Jack feels strongly that he was not.

Interactional Analysis

Even a superficial glance at the transcripts of this team's discourse reveals that Jack dominates the conceptual roles and thus the generation of ideas. Often Jack speaks for long stretches, as a traditional instructor might at a blackboard, with Yass asking a question now and then to check her understanding. Jack obviously knows his subject well, and he has the freedom to explore and develop his thinking. His turns often sound like think-aloud protocols—that is, they are self-directed and somewhat private. In contrast, any conceptual ideas that Yass volunteers are rare, usually brief and tentative, and team directed. They are also derivative in that they rise from a last word or phrase in Jack's previous turn. In other words, Yass's contributions do not emerge from deep understanding of the topic, but from whatever Jack has just finished saying. (Occasionally, however, she will sum up a few of Jack's points.) Yass is aware that Jack has greater ambitions for the project than she has, and many of her comments and questions reveal a desire to keep the project as simple as possible. She is not afraid to disagree with Jack, and there is sometimes a little tension between them in regard to project scope, with Jack ready to enlarge it and Yass ready to restrict it.

Interaction 1: Comparison of Typical Partner Contributions

The following sample of their interactions exemplifies most of the dialogue when Yass is attending closely. (In some sequences when Jack's turns are long, her presence seems to vanish, or she appears not to be listening.)

J: The idea is that X-10 devices are passive *[Expla]*. They only listen, they don't send anything *[Expla]*.

Y: Okay *[Res]*.

J: So we have to work around that a little *[Reg]*. So that we can send–*[PI]*

Y: –Okay *[Res]*.

J: –with our devices *[Expla]*. But here's all the codes *[Pres]*. See, there's only enough for 255 devices, because it's house A through house P and then there's 16 units per house *[Pres/Expla]*. So you have, what is it? 16, I guess, probably? *[Expla]* 3 yeah, it's 16 per four bits, so there's 16 different codes *[Expla]*, different groups, and 16 devices per group *[Expla]*.

Y: Okay *[Res]*.

J: And then these are like commands *[Pres/Expla]*, all units off *[Expla]* This works for everybody, this works for everybody, and then one, I think, like goes with a house *[Pres/Expla]*. You send all the ones in the house on or all the ones in the house off, all the preset dims, all the lights off *[Expla]*. I'm not sure about that *[Ev-S]*.

Y: [word] *[Unc].*

J: But, now this preset dim, if you go to Note 2 *[reads]* "preset dim function represents the most significant byte of the four bit. The house code represents the four least significant" *[Pres]* This is the most important part: *[Ev-R]* *[reads]* "No known extend device responds to that function" *[Pres].*

Y: To that dim function? *[Req-Cf/Expli-P]*

J: So I was thinking–*[PI]*

Y: We can– *[Unc]*

J: –we could use this in the extended data to uh implement whatever extended functionality we wanted to add *[Prop]*. The extended data is just, you send this, then afterward you have eight bits you can send of data *[El-S]*. So, like, with the extended data, like we send extended data to our device and then in our eight bits, we could say we have three bits to define like a control, or something *[El-S]*. Then after that, whatever data you need, or maybe just zeros because we don't need anything. *[El-S]*

Y: Okay *[Res]*.

J: So, basically, the hardest part of doing this is going to be making *[Ev-Ta]*, we need to try if we can to make our software so that it works uh so that it works in the simulation *[Reg/Prop]* and then when we take and plug our, our output into a circuit, that puts it onto an AC line *[Expla]*.

Y: Uh-huh *[Res]*.

J: If we get that far *[Ev-Te].* We need to make, we need to try to make our software so that we don't have to do anything to it to make it, to take that step *[Reg]*.

Y: Okay, so basically, it will be all software and then if we have time we'll go and build more hardware to it? *[Sum/Req-Cf]*.

J: Yeah. We'll be, we'll be uh linking all these things together and we'll probably have to build control circuits, of course, to turn on and off the devices *[Reg]*, but it's really not that much to it as far as the hardware goes *[Ev-Ta]*.

Y: [word] control circuit will be very simple, right? *[Req-Cf].*

44 J: Very simple *[Ev-Ta]*.

Interactional Focus: The partners are discussing the design of the overall system components. The interactional focus is Project Goal.

Interactional Roles and Cooperative Patterns: Jack initiates the topic. (Actually the interaction is taken from a long sequence of interactions in which Jack is moving from topic to topic as they occur to him.) Yass responds with a continuer, and most of her turns consist of continuers. Jack is at a whiteboard as he talks, and as Presenter/Explainer he draws out the design as he sees it. For most of the interaction, Yass is more or less a patient listener, neither agreeing or disagreeing. Jack's roles are uniformly Conceptual; only he is introducing new information for team consideration. In Line 21, Yass breaks pattern by checking her understanding (Requestor-Confirmation/Explicitator-P), and from that point she is primarily confirming what she has heard. Notice in Line 23 that Yass attempts to interject a thought, but it is completely lost in the sweep of Jack's verbalizations and it never comes up again. In Line 38, Yass sums up her understanding of Jack's ideas. Overall Jack's roles vary, but they are predominantly Conceptual or Team Regulation, while Yass's roles are meant to keep her aligned with Jack (but not vice versa). A summary of roles is as follows:

Jack: Explainer, Regulator, Presenter, Analyzer, Evaluator-Self, Elaborator-Self, Proposer, Evaluator-Task, Evaluator-Team, Querier, Reporter, Specifier

Yass: Responder-Neutral, Requestor-Confirmation, Summarizer

From the disparity in substantive roles, the interaction is asymmetrical. The partners seem to be aligned in understanding. In fact, Yass's contributions are mainly her attempts to confirm that she understands correctly. There is no explicit disagreement. From those bare descriptors, therefore, the interaction is Acquiescent Co-Elaboration (but see the discussion below).

Discussion: Acquiescent Co-Elaboration may be too good a category to describe this team's cooperative form. It would be questionable to consider Yass's comments as constituting feedback, which is necessary for co-elaboration. Her comments in no way guide or modulate Jack's thinking, nor do they enhance team understanding, nor do they figure into team decision making. She learns no more than what she can understand from Jack, and Jack learns no more than what he can figure out himself, and there is little interchange of ideas. Whereas Co-Elaboration in Application Study 1 seemed to have a mutual effect on the participants, in the case of this team, Jack's monopoly of the reasoning process seems to render Yass's presence superfluous. Yass does speak up in Line 43, where she seems to be concerned about keeping Jack in bounds and the project simple. This type of monitoring—keeping things simple—seems to be her main role. Otherwise, as in this interaction and those before and after, the project is entirely in the hands of Jack, and Yass is an onlooker. Perhaps this interaction could better be categorized as *quasi-collaborative*.

Interaction 2: Differences in Project Views

Whenever Yass contributes a substantive turn, there is usually some evidence that the partners are misaligned or speaking at cross-purposes, which leads to even more explanation from Jack. For example—

J I tried to add some functionality to the existing X-10 protocol, but it's not going to be real easy. I don't know. There're some definite problems. Like, I want it to work within the existing framework of the protocol without breaking it. And there's some problems with that, but essentially–

Y –Oh, okay, so instead of having the X-10, we're going to uh to build or extend or write software.

J [pause] We're going to write the software to run the X-10. In other words, we're going to have to write a module for send and a module . . . .

Another example:

Y Do you think it will be a current, like, you know, like when the uh, you know, the whole thing may cross cross at this point? We can send it?

J Do you think it will be hard? What do you mean?

Y It won't be that hard. I mean, will it be, will it be accurate enough to–

J –Accurate? Well, I think, I'm not positive what you mean. How this works? Probably what it would be is, like, we have a circuit that has in, the data in, right? *[drawing]*

Those interchanges, which are typical of many in the transcriptions, indicate that Yass is sometimes not certain about Jack's train of thought, has trouble finding the words to contribute on his level, or both of those. In addition, there seems to be a difference in the way the partners envision the project scope. As the following interaction seems to show, Jack is open to exploring alternatives, even enlarging the project, while Yass is more intent on keeping the project simple.

J Say we didn't have time, we could just buy this transmitter and then demonstrate that our existing additions to the protocol worked with the existing, extended X-10 *[Prop/Reg]*.

Y Okay, what does that protocol do? *[Req-I]* Because ours, the way we'll be writing our routines is, you know, how to, to notice the one those AC voltage, right *[Req-Cf]* And then send a pulse on that *[Req-I]*.

J Well, no *[Res-]*. We're going to have to, we're going to write our routines general enough that- *[PI]* It's not going to know- It's not– We're not going to actually do, like in the actual routine *[Reg].* It's probably going to be looking at a port *[Expla]*, and it's only going to read– *[PI]*

Y Okay, okay, okay *[Res+]*. Just a one or whatever and maybe the device and a one or some kind signal *[Sum]*.
J *[Pause]* Yeah *[Res+]*. So we're going to have to write our routines general enough *[Prop/Reg]* so that it just doesn't dump all the data on there at once *[Expla]*. It, like, waits and then it sends, then waits and then it sends, and waits and then send kind of thing *[Expla]*. . . .
.
. *[Several minutes of explanation.]*

. But to be able to have it work right, that's what we need to do *[Reg]*, just how it is *[Ev-Ta]*.
Y Okay *[Res]*. And if we get, if we, you know, if we get the protocol, what does it, what does that do? *[Req-I]*
J What, the box? *[Req-Cf/Expli-P]* That just takes the commands, and it puts it on the wire for you, on the electrical outlet wire *[Expla]*. However, I'm not sure if it uh does any encoding for you *[Ev-R].* Like, if you send it one command, if it does it three times or not *[Ev-R]*. Probably it doesn't *[Ev-R]*. Probably you have to– *[PI]*
Y –If it does, that would be good *[Ev-R]*.
J That would be, well, it would be bad *[Res-/Ev-R],* because then we would have to change what we wrote in the first place *[Expla]*.
Y *[Pause]* Okay. *[Pause]* No, then we could first we can take the protocol, you know, and. . . . *[Prop/Reg]*
J Could be, yeah, *[Res+]* I mean, but that's– *[PI]*
Y –You don't want that way *[Ev-P]*. You want the whole thing to be done in the software *[Ev-P]*.
J Kind of the point of it is to have it done in software *[Mon-S/Just]*, that we're hooking, we're hooking like– *[PI]* Instead of using a dedicated device *[Reg]*, like I know you were asking–*[Ev-P]*
Y –How, how complex the protocol? *[Req-I]*
J The protocol? *[Req-Cf]*
Y Yeah *[Res+]*.
J Like uh [reads] Firecracker Home Control Kit *[Pres]*. The Firecracker Interface, let's see *[Pres]*. *[Reads to himself].* Yeah, okay, virtual remote interface. . . *[Pres]* This is existing *[Expla]*. It's all manual *[Expla]*. You set it *[Expla]*.
Y Okay *[Res]*.
J Like I was saying *[Expli-S]*, it's like if you have it stored inside the 6811, and then you could set it with software from your computer *[Prop]*, that would be cool *[Ev-Ta]*. Because then you could move the groups around *[El-S]*.
Y You're *[unintelligible] [Unc]*
J What? *[Req-I]*
Y You're in too complicated *[Ev-P]*. They're not that costly *[Ev-R]*. Keep our software simple *[Reg]*. Very simple software *[Reg]*.
J But the idea of software is software is cheap *[Just]*. Components are expensive *[Just]*.
Y Okay, okay *[Res]*.

Interactional Focus: The partners are discussing the configuration of the system, specifically, how operations might be handled by dedicated hardware or might be handled by software. The interactional focus is Project Goal. From Line 48 to the end of the interaction, however, the focus wavers between Project Goal and Project Team as Yass observes that Jack is intent on taking a particular approach to the problem solution, an approach she does not necessarily agree with.

Interactional Roles and Cooperative Forms: Jack is discussing an alternative, when Yass asks for an explanation of the protocol. In Lines 3-5 she (Requester-Confirmation) attempts to confirm her understanding of how the system works, but in Lines 6-9 Jack (Explainer and Regulator) refutes her description, and Yass remembers what they had discussed before and agrees. Jack expands his answer into a lengthy monologue, but in the end, Yass (Requester-Information) is still puzzled about the protocol (Line 20). Again Jack stumbles over the question (Line 22), but this time he answers more directly. Even so, Yass does not catch the full import of the answer and assesses a possible protocol operation incorrectly (Line 26), or at least in a way that does not conform to Jack's plans for the project. In Line 32, the interactional focus shifts as Yass (Evaluator-Partner) makes the observation that Jack's seems to be emphasizing the use of software in the project design. Jack (Monitor-Standards/Justifier) defends his approach (Lines 34-36). Yass asks pointedly about the complexity of the protocol (Line 37), and Jack's answer (Lines 40-42) that the remote interfaces are manually set seems to her to confirm her idea that the use of extra devices would be a "simpler" approach than writing more software. Unfazed by Yass's implied disagreement, in Line 44 Jack (Proposer, Elaborator-Self) resumes his plans for writing the software that would give the system more flexibility. Then, in Line 49, Yass (Evaluater-Partner, Regulator) makes the personal comment that Jack is making the project too complicated and argues that they should keep the software simple. Jack (Justifier) justifies the use of software on the basis of its low cost, and Yass acquiesces (but is perhaps not in full agreement).

A summary of the roles contributed by each partner is the following:

Yass: Requestor-Information, Requestor-Confirmation, Responder-Agrees, Summarizer, Responder, Evaluator-Resource, Proposer, Regulator, Evaluator-Partner

Jack: Proposer, Regulator, Responder-Disagrees, Explainer, Responder-Agrees, Evaluator-Task, Requestor-Confirmation, Explicitator-Partner, Evaluator-Resource, Monitor-Standards, Justifier, Presenter, Explicitator-Self.

Jack has a larger variety of substantive roles and brings new information to the team's awareness, even though there is little evidence that Yass is following everything he says or that she shares his enthusiasm for his ideas. Thus, the interaction is asymmetrical. In general, these partners are not in alignment. They are thinking somewhat independently of each other, and where their thinking intersects, there is conflict. Without symmetry, alignment, and agreement, this interaction suggests that the cooperative form is Apparent One-Sided Argumentation.

Discussion: This interaction shows Yass at her most assertive. Usually she is content to let Jack talk on about his ideas with only a request now and then for clarification. On the other hand, this interaction is typical insofar as many of her contributions are attempts to rein in her partner’s tendencies to enlarge the project goal or complicate the path for getting there. Jack’s superiority in knowledge allows him to imagine many alternative solutions for the project, but Yass is somewhat in the dark technically and can only react to Jack’s ideas without countering them with any of her own. In other words, Yass does not have a sufficient understanding of the project to argue concepts; she can only attempt to keep the project within bounds, much as a manager might do. For that reason, the conflict between these two partners appears when both are taking Project Regulation roles, not Conceptual roles.

Consequently, from the beginning of the interaction, Yass seems to be preparing an argument for keeping the project simple, that is, to rely less on software (which must be written) and more on hard-wired devices (which can be purchased). Her contributions represent a subtext to Jack’s wider-ranging expositions, therefore, and her line of thought engages with Jack’s line of thought only at particular points in the dialogue (Lines 32 and 49-50). When conflict emerges, Yass is weak in the defense of her viewpoint; Jack is much better equipped with domain information, and he has the language proficiency to state his argument concisely and convincingly.

Conclusion of Application Study 3

This application study analysis has attempted to describe a team’s operations from information gleaned from only three sources: the Task Preference Profile, the Project Satisfaction Profile, and the interactions themselves. The Task Preference data indicated that neither partner was particularly interested in performing management or regulatory tasks. Consequently, the team's project operations were expected to be deficient in those functions. To a degree, that is true according to the interactions. Only Yass shows an occasional attempt to regulate the project, but those attempts are rare, somewhat halting, and usually leveled at her partner's tendencies to expand the project or add complexities. On the other hand, according to her profile, Yass indicates that she enjoys technical work, more so even than Jack.

Jack's contributions are somewhat self-directed; in some portions of the interactions he seems to be talking even though he is aware that his partners is not entirely understanding. He shows little of Dan's patience and willingness to pass control of the planning to his partner (Application Study 1), nor do the two partners exhibit the spontaneity, easy alignment in thinking, or general underlying agreement so apparent in Sam and Greg's dialogue. There is little doubt that Jack is capable and knowledgeable, but his domination of knowledge generation distorts the teammanship quality of the joint effort. The team does not work as a system of interdependent parts, so that cooperative forms are either quasi-collaborative or Apparent One-Sided Argumentation, neither of which is likely to foster the degree of *team* learning that the other cooperative forms provide.

CONCLUSION OF APPLICATION STUDIES

This chapter has presented three application studies that together show some of the variety of cooperative forms used by pairs of engineers as they work on design problems. Each team revealed a unique mix of cognitive and communicative properties, and each team either capitalized on those properties or worked around them in some way. For

Application Study 1, the cooperative form was predominately Co-Elaboration. The well-matched pair in Application Study 2 was able to achieve a mutuality that enabled Co-Construction. In Application Study 3, the communication difficulties and lack of team-directed management/regulation functions precluded opportunities to benefit maximally from collaboration. The prevailing cooperative form was Apparent One-Sided Argumentation or some form of co-presence that can only be called quasi-collaboration, and the result of the project seemed to be little more than what one partner, Jack, could have accomplished alone.

For each application study, the descriptive frame described in Chapter 3 provided a systematic approach that combined considerations of certain conditions (properties of the partners in regard to task preferences), certain outcomes (properties of the partners in regard to satisfaction with cognitive and communicative performance), and interactional processes (conversational roles and cooperative forms or patterns). This breadth of reported and observed information, which derives from the partners themselves or arises from within the actual collaborative experience itself, proved indispensable in the interpretation of the interplay of cognitive and communicative behaviors, and in fact showed that each of these two types of behaviors cannot be well understood with reference to the other. Particularly revealing were the comparisons of partner satisfaction with Team Communication, Individual Technical Performance, and Team Technical Performance, even without the interview data as in Application Study 3. The next chapter discusses this point in more detail.

CHAPTER 6
DISCUSSION AND CONCLUSION

FINDINGS OF THIS STUDY

The findings of this study support Hutchin's contention that an understanding of interactions requires knowledge of the properties of the interactants and the outcomes of the interactions, as well as processes within the interactions themselves (Hutchins, 2000). Those findings, as they relate to the research questions of this study (see Chapter 1), are given below.

Types of Cooperative Forms

This study has demonstrated that Baker's descriptive model of problem-solving interactions is an effective framework for discerning and describing cooperation within two-person design teams. The application studies show that the distribution of conversational roles (Proposer, Explainer, Explicitator, and so on) between partners during an interaction is a general indicator of the degrees of symmetry, alignment, and agreement within their problem-solving efforts. Symmetry, alignment, and agreement, in turn, are factors defining the cooperative forms the teams integrate into their interactional patterns. Examples of cooperative forms observed in this study are Acquiescent Co-Elaboration (Application Study 1), Co-Construction (Application Study 2), and One-Sided Argumentation (Application Study 3).

This study shows that, while the interactive behaviors (roles, cooperative forms, etc.) may differ from team to team of collaborating engineers, those behaviors within any single team tend to be fairly consistent at least over the planning stages of a project; that is, the team partners seem to settle early into a pattern of interactions that may or may not be optimal for both partners. The conversational roles and hence the types of cooperative forms that appear may depend on the relative expertise of the interactants, the difficulty of the problem, the relative willingness of the interactants to perform team management or regulatory functions, and the focus of the interaction (Project Goal, Project Mediation, or Project Team).

Differences in Engineering Task Preferences as an Interactional Condition

From the results of the Engineering Task Preference Questionnaire, this study determined that student engineers differ in their preferences for or identification with the various types of engineering tasks. Those types can be categorized as Management-Corporate activities, which comprise more communicative and socially involved tasks; Microtechnical activities, which involve more individually oriented technical tasks; and Higher Professional activities, which refer to tasks that are more career and discipline oriented, such as giving papers at professional conferences. Of course, some student engineers may score high or low in two or all three of those categories, but generally undergraduate engineers are not yet enthusiastic about many of the activities that mark mature or successful careers.

Furthermore, this study shows that many student engineers prefer individually oriented technical tasks over communicative and socially involved tasks, while for many others those preferences are reversed. Knowledge of how those preferences are distributed in a given team, along with the quality of contributions to interactions, helps in determining why student engineers assess their projects as successful or not.

Relationship of Task Preferences to Team Interactions

The study suggests that collaboration in complex design problems requires that at least one partner assume Project Regulation and Team Alignment roles. In the Task Preferences Profiles, therefore, those application study partners who scored high in Management-Corporate task preferences were also those who worked to improve the team conditions for problem solving (for example, Greg in Application Study 2) or scaffolded the learning of his partner (Dan in Application Study 1). Those partners seemed team- or partner-oriented to a substantial degree, and their partners had the latitude to take on the roles that allowed them to contribute effectively and test themselves as problem solvers. In contrast, neither of the team members in Application Study 3 expressed a preference for Management-Corporate activities, and perhaps partly for that reason neither partner consistently performed the regulatory roles that would have maintained or improved team symmetry and alignment.

A positive regard for Microtechnical activities seems to indicate the partner's propensity to delve into problem details. If one partner scores considerably higher in this category than the other, then the potential exists for the first partner to take the initiative or play dominant Conceptual roles in Project Goal interactions—if, that is, the partners are generally equal in prior knowledge. A comparison of the score in this category has particular meaning when it is compared to the scores in the Project Satisfaction Profile, especially the score in the Individual Technical Accomplishment factor category. For example, if a partner scores low in preference for Microtechnical activities and high in satisfaction with Individual Technical Accomplishment, the team interactions may well have provided that partner with learning opportunities. If those scores are reversed, however, the collaborative relationship somehow prevented the partner from working at his or her full potential.

Participant scores in Higher-Professional activities were uniformly low, or at the best neutral. Attending conferences and publishing articles seemed outside the horizon of career possibilities in the ambitions of the undergraduates participating in this study.

As remarked above, an important and general finding is that scores of a Task Preference Profile should be interpreted only in conjunction with scores in the Project Satisfaction profile and with evidence from the interactions themselves. For example, a comparison of the Management-Corporate preference score with the Team Communications satisfaction score suggests the degree to which the partner was able to meet his or her self-expectations in team discourse. In addition, scores in one partner's profile should be compared with the scores of the partner. Any reversal in the relationship of the scores between preferences and performance may suggest the degree that an individual was able to perform within the partnership and whether that performance is at the expense of the other partner, as in Application Study 3.

Differences in Project Satisfaction as an Interactional Outcome

This study used the Project Satisfaction Questionnaire to identify the degree that the participants felt positive toward the communicative and cognitive aspects of their projects. The Project Satisfaction Profile, which consolidated those aspects into factor categories, revealed in many cases sharp differences in the way partners viewed their project. Five of the eight categories, or aggregate factors, were especially useful in the interactional analyses of this study: Team Communications, Individual Technical Accomplishment, Team Technical Accomplishment, Communication Confidence, and Participation. The other three factor categories also provided essential information, especially in Application Study 3, which included a nonnative speaker of English. Those factors are Communicative Awareness, Communicative Assistance, and Communication Improvement.

These factor categories identified project outcomes based on the participants' attitudes toward their project and not on any quantifiable or repeatable measure. Nevertheless, participant attitudes are likely to be important indicators of other types of project outcomes, such as productivity and the quality of the final design product. In addition, the qualitative measures are better able to penetrate into the processes at a deeper, interactional level in the psychological space of the team problem solving.

The outcome categories revealed partner differences along two axes: satisfaction with team and individual technical performance and satisfaction with team and individual communicative performance. It should be emphasized, however, that descriptions of cognitive (technical) behaviors or social (communicative) behaviors independently of each other will produce dubious results (Perret-Clermont, Perret, & Bell, 1991). The application studies clearly demonstrate that, in collaborative engineering problem solving, those types of behaviors are different manifestations of the same sociocognitive process.

Relationship of Project Satisfaction to Team Interactions

The study indicates that an interpretation of the interactions in light of the scores of the Project Satisfaction Profile must consider various relationships among the factor categories. For example, the scores for Team Communication, Individual Technical Accomplishment, and Team Technical Accomplishment should be considered as a set. In Application Study 3, for instance, Jack recorded high scores for Team Communication and Individual Technical Accomplishment, while he registered an extremely low score for Team Technical Accomplishment. That configuration of scores is a strong indication that Jack believed he could have worked better alone. In fact, the evidence from the interactions is that in effect he was indeed working alone to a large degree, partly because he entered the project with the advantage of considerable prior knowledge and partly because his domination of the flow of ideas effectively limited Yass's participation to passive roles in the discourse. On the other hand, Yass's exclusion from playing important conceptual roles is reflected in her extreme dissatisfaction with Team Communications. For those reasons, the interactions of this team reveal little actual collaboration taking place, or if it does, it takes the weakest of cooperative forms, that is, Apparent One-Sided Argumentation.

In the application studies whose partners both report satisfaction with Team Communication, one or both partners were found to frequently assume Project Regulation and Team Alignment roles in their interactions, and they devoted some interactions to Project Team topics. If one or both partners report dissatisfaction with Team Communication, then the team interactions are likely to contain little evidence of regulatory or alignment activity in the discourse.

Overall, each team is unique in its mix of communicative and cognitive resources, and each team requires its own analysis. The framework described in this study is not a predictive model, though it does attempt to relate certain configurations of profile scores with cooperative forms. The framework primarily organizes information about the partners—their task preferences and their project satisfaction—and information about their interactions—symmetry, alignment, and agreement—in such ways that relationships among factors and behaviors can be discernd and perhaps interpreted in terms applicable to the particular team.

OTHER CONTRIBUTIONS

This study has applied Baker's descriptive model of dyadic problem-solving to an analysis of interactions between student engineers engaged in real-world engineering design problems. The design problems were of such a length and complexity that they required interaction at several levels: Project Goal, Project Mediation, and Project Team. Consequently, the team projects provided practical testbeds for the descriptive model.

In addition, the current study has enlarged Baker's model to include factors of task preference and project satisfaction. With this more comprehensive framework, the study was able to relate team cooperative forms with the properties of the participants and outcomes of their project. By taking these various relationships into consideration, the study brought to light more interpretative data than analyses of team interactions could reveal alone. This integration of task-preference data, project-satisfaction data, and Baker's schema of interactional dimensions and cooperative forms is a novel approach to the study of problem-solving interactions in work settings.

The strengths of the framework, therefore, is that the components rely on information that (1) has been drawn from engineers themselves, (2) rises directly from the design experience, (3) exemplifies actual engineering discourse, and (4) takes a step toward observing the interrelationships between cognitive and communicative activity during design problem solving.

Because the design problems were complex and lengthy, the study was able to observe team partners using regulatory, monitoring, and alignment roles to build their common ground (Clark & Brennan, 1991). Of special interest are the roles of Explicitator and Monitor-Alignment. Whereas Baker refers to explicitation as the process of rendering explicit one's "underlying reasoning and knowledge" during argumentative exchanges (Baker, 2002) p. 32), this study used the term to signify partners' attempts to "make explicit" their own or their partner's ideas to discover where and how their thinking is the same or diverges. This process occurs not only in argumentation, but in co-elaboration cooperative forms as well. For the team in Application Study 1, essentially coelaborators, the Explicitation role led to discovery for both partners, who by simply making clear and emphatic what they both thought they were hearing or saying, were able to see the issue from different perspectives. There was not so much an attempt to agree as there was an attempt simply to understand what each other was thinking by expressing it in their own words and asking in effect "Am I wrong?" The Monitor-Alignment role also fostered mutuality in the application study projects and allowed the team to operate on a higher plane.

The study also indicated that, either by default or by decision, at least one partner must assume regulatory roles in large collaborative projects, roles such as Monitor-Standards and Regulator. This division of responsibility is probably the most basic of the team's working relationship, for it means that at least one partner is aware of the conditions, resources, and general direction of the collaborative efforts. If the other partner is more conceptually oriented, then the functions of a "manager" are all the more necessary.

In summary, as the complexity and length of collaborative problems increase, more instances of Team Regulation and Project Team interactional roles can be expected to appear in the conversations of engineers. If those roles do not appear, then the chances are good that either the partners will go adrift together, or that collaborative efforts will be abandoned for more self-directed efforts.

LIMITATIONS OF THIS STUDY AND THE NEED FOR FUTURE RESEARCH

Researchers have noted the lack of longitudinal investigations into the collaborative behaviors of adults engaged in long-term, ill-defined problem solving (Barron, 2000), and that lack has led to many unresolved questions that this study could only partially address. For example, much is to be learned about how relationships of working partners evolve over time. The investigations of this study focused on interactions during the definitional and planning stages of the project. Partners, however, may mature in a project in different ways, role patterns and cooperative forms may change, and divisions of labor may lead to less co-construction and more work in parallel (when the partners more or less report to each other).

The framework developed in this study was applied to pairs of engineering problem solvers. An important line of investigation would be to determine how the framework can be modified to apply to teams of three of more engineers. Baker (2000) offers suggestions about determining symmetry and other dimensions as they apply to larger groups. The addition of the task-preference and project-satisfaction factors, however, complicates matters; yet, those factors may add important insights into how larger groups develop and maintain productive cooperative patterns. In other words, just as this study has attempted to do for dyads, later studies may attempt to discover how "patterns of communication could produce particular cognitive results" (Hutchins, 2000, p. xvii) in larger teams.

This study, though adhering to the spirit of distributed cognition, does not address the "transformation, and propagation of representational states across a variety of media" (Hutchins, 2000, p. 49); that is, it does not address how an item of knowledge undergoes change under the mental ministrations of the student engineers. The "system" in this study—or the unit of analysis—is the problem solving team itself: two people with distinct properties, with distinct ways of interacting, and with distinct outcomes. Further work using the framework in this study might include the quality of the design product (the representation) as one of the outcomes. Good collaborative practices may be necessary, but not sufficient for the success of the design product; if so, further studies may reveal other interpersonal factors or relationships related to product success rather than project satisfaction as the outcome.

Some of the interactional roles used in this study were based on those in Hogan et al. (Hogan et al., 2000; McIlwee & Robinson, 1992). Those authors, in their study of discourse patterns and collaborative reasoning processes in peer- and teacher-guided discussions, identified and labeled a number of types of statements made by eighth-grade students while collaboratively attempting to construct mental models of the nature of matter. Because of the vastly greater complexity and multileveled nature of design discourse, the current study had to modify, expand, and reorient those statement types. In addition the statement types were transposed into the names of interactional roles. Thus a “proposal” becomes a “Proposer.” Not all of the roles could be defined precisely enough to avoid ambiguity and overlap; human discourse will always be bigger and more complicated than any list of labels that attempts to define it. This area of the study could always be improved.

This study has not addressed issues of artifacts and their effects on team collaboration. Yet it was obvious in the application studies that the team partner who has his or her hands on the LCD or keyboard gets to decide on the interactional topic and is more likely to take on important roles like Presenter or Elaborator. Situational factors such as those figure into this study only incidentally. Finally, an important area of research is to determine how the concepts of symmetry, alignment, and agreement and the cooperative forms they compose relate to the group learning processes described in Chapter 3. Baker (2002) makes several convincing links between argumentation and conflict resolution and between alignment and social grounding. There are, however, many others, such as (self-) explanation, mutual regulation, and shared cognitive load, that could be associated to types of interactional roles and cooperative forms. The framework developed in this study may be useful in furthering those investigations.

The development of the analytical framework described in this study and its application to the interactions of problem-solving dyads are attempts to open a few more theoretical and methodological windows into the complex world of small-group collaboration in engineering. The study does not attempt to make a set of definitive statements about engineering design itself, but rather to test a systematic approach to the study of how some engineers work together some of the time. For that reason, the approach has been mainly qualitative (loosely, a discourse analysis aided by descriptive statistics). The use of experimental designs, which require proper controls and aim at generalizable results, are of course essential for research into narrow, well-defined, and quantifiable aspects of design team interactions; however, the use of the qualitative methods is valuable in that it allows the observation and interpretations of interactions as they spontaneously unfold with all their unpredictability and variability.

With that strength, however, there is also a weakness; strictly speaking, the findings of this study can be said to have meaning only in regard to the application studies examined. Nevertheless, the findings draw our attention to processes and behaviors as they occur under actual conditions, and they are likely to appear again in different teams, under different conditions, and in different combinations. For that reason, the findings of this study may point research in directions that eventually yield benefits of the more predictive and prescriptive kind.

The study based its investigations on psychological and developmental aspects of collaborative learning, with an important idea or two from cognitive science in regard to design problem solving and distributed cognition. In the last decade, a great amount of interest has turned to the use of computers to support collaborative work. Indeed, in the future computers may well be our collaborators in design teams, figuring into the joint decision making along with their human partners. Any success in developing a computer-assisted collaborative environment, however, will require knowledge about human-human collaboration, knowledge that we currently do not have in sufficient detail (Dillenbourg, 1999a). More information is required, for instance, about the socio-affective aspects of collaboration (Barron, 2000). In the current study, team conditions were limited to considerations of team member preferences for types of engineering tasks, and the effects of collaboration were limited to the partners' perceptions of their own satisfaction with the cognitive and communicative aspects of their project. It may be possible someday for computers to assess and monitor those same factors among its human partners and make "team" decisions that take them into account. Still, there are other factors, such as social differences in culture, gender, language proficiency, and individual differences in motivation, work ethics, leadership—all of these variables play a large part in the ability of two or more humans to work together, yet they are difficult to model. If computers are to join the company of humankind, then computers are going to have to learn to cope with those variables the same as we humans do.

Finally, the question remains about the validity of the Task Preferences Questionnaire for this study. Any subsequent study exploring the use of the interactional framework would do better perhaps to devise a questionnaire or other means for collecting task preference data that better suits the participants' actual experience, rather than their expected, predicted, or desired experience.

CONCLUSION

Instructors (and managers) observing teams at work should be alert to the need for signs of symmetry, alignment, and agreement in a team's collaborative behaviors and to be aware of possible ways to build on those strengths or compensate for their absence. They should be able to understand how a team engaged in a long-term project is responding to interpersonal differences, say, in knowledge or management practices, and to help the team adjust their relationships to enhance the collaborative spirit. Instructors who are able to assess interactional roles and cooperative patterns are in a better position to advise the teams, while being sensitive to the properties of its members. Finally, instructors (or managers) overseeing team projects should be able to evaluate the outcome of group work and be able to explain to the students (or adult workers) reasons for their positive and negative attitudes to a team experience. In that way, a team project is not merely an assignment in a course or a task on the job, but a unique learning experience.

Theories of education constantly undergo revision, reform, and even revolution, but since the discovery of the ideas of Piaget and Vygotsky, at least one basic tenet of education has remained stable and in the forefront of research: children—and adults—learn, work, and solve problems in social settings. It is not surprising, therefore, that engineering schools, which produce society's premier problem solvers, have begun to stress the importance of small-group decision making and problem solving. For instance, the prestigious overseeing body of U.S. engineering schools, the Accreditation Board of Engineering and Technology (ABET), stipulates that any engineering educational program receiving its cachet must demonstrate that its graduates can "work in collaborative, multidisciplinary teams." The word *multidisciplinary* implies that graduating engineers must be able to work effectively in group environments in which no few group members can possibly have all the domain knowledge and skills necessary to meet the group's goals. Solutions are necessarily combinations of the ideas and knowledge of many professionals working together.

While it is important that engineering students learn to build effective collaborative working relationships in multidisciplinary environments, it is not enough for engineering schools to occasionally assign students to teams in the classroom, hand them a problem, and give them a deadline for a solution. As this study suggests, potentially good problem solvers may fail as a team, and excellent collaborators may fail as problem solvers. They need to be able to articulate why their team efforts succeed or not, and that type of insight requires frequent opportunities to test themselves with others. In a word, cognitive skills and communicative skills must be learned together—beginning as early in the engineering curriculum as possible. By the time student engineers graduate, they should have already acquired collaborative experience with as wide a range of partners as possible. The ultimate goal in engineering education, therefore, is to give students the opportunity to learn a basic fact: success in their careers is not so much a matter of their outshining others; it is more a matter of their creating the intellectual and social conditions by which they and their team partners can shine together.

APPENDIX A
GENERIC FEATURES OF DESIGN PROBLEM-SOLVING
(GOEL & PIROLLI, 1992)

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(GOEL & PIROLLI, 1992)

1. Structuring the problem: Problem structuring takes place early in the project, but recurs frequently as new information or developmental issues dictate that the designers refine the way they understand the problem. Typically, problem structuring includes statements about the people involved, the purpose of the project, and primary informational and equipment resources. Most of the communications at this point are oral, indicating a reluctance to commit to any design ideas at this preliminary stage. Many of these communications are in the form of proposals, questions, or "what if" statements. Finally, the designers call forth from long-term memory the general and domain knowledge applicable to the problem.

2. Dividing problem solving into phases: Problem-solving activity moves through three phases (not including problem structuring): preliminary design, refinement, and detail design. As the designers proceed, their references to the people, purpose, and resources involved in the project decrease, and their willingness to commit verbalizations to paper increases. Their primary source of knowledge shifts from the client or problem statement to experts and printed texts, and eventually the designers require no external information whatever.

3. Reversing operations (transformation function): *Reversal of the transformation function* is Goel and Pirolli's term for the designers' attempt to redefine the project goal into one that the designers can more easily achieve, given the level of their expertise and prior knowledge. This attempt, which may require negotiation with the client, represents a revision to the problem statement, so design efforts seem to be working backwards. Go dog go.

4. Decomposing the design into modules and controlling/coordinating module designs. In this strategy, designers decompose the problem into modules. The modules may be "leaky"; that is, they are not completely interconnected to other modules during the course of the project. Instead, the designers monitor the interconnections to ensure compatibility. Because the interconnections can be complex, designers tend to employ what Goel and Pirolli (1992) call "limited commitment mode control strategy." With this strategy, designers do not have to complete a given module before starting another. Instead, they leave the module in a state of incompletion while they attend to other modules, and then they return to the first module when they know more about its interconnection requirements.

5. Developing the artifact in increments. Designers continuously refine interim solutions as the design unfolds. They seldom forget or discard earlier ideas or

proposed solutions, and they bring earlier ideas back into play when new information gives them new applicability.

6. Committing to design decisions: As project timelines near, designers must commit themselves to decisions that they may feel are less than ideal, but nevertheless have practical promise. Decisions made in one area of design generally have a cascading effect on decisions on other areas of the design.

7. Determining when enough is enough. Because of the lack of evaluation and feedback from the outside world, the designers must create their own stopping rules. These rules will differ from designer to designer and from expert to expert.

8. Relying on memory retrieval. Design problems are not "logic problems"; consequently, designers rely primarily on personal memory and information sources for their solutions and only secondarily on deductive reasoning processes.

9. Modeling prototypical solutions: Models (for example, mathematical models or small-scaled physical representations) allow designers to test solutions, refine details, and discover problems before committing time and expense construction.

10. Use of different levels of abstraction. Whereas the input specifications describe the function of the artifact and the output describes the construction of the artifact, the design activities focus on how the artifact is to operate. Thus, to the client and the user, the artifact is a blackbox. The designer, whose work must take into account function, construction, and operation together, must be able to move back and forth among these various levels of abstraction within a consistent hierarchy.

11. Use of symbol systems. Designers use symbol systems (sketches, notes, schematics, flow charts, utterances, equations, and so on) extensively to help them plan and control activities, to visualize processes and relationships, to reduce the demands on memory, to ensure compatibility between components, to eliminate redundancy, and so on.

References for Appendix A

Goel, V., & Pirolli, P. (1992). The structure of design problem spaces. *Cognitive Science, 16*(3), 395-429.

APPENDIX B
SUMMARY OF PARTICIPANTS

APPENDIX B
SUMMARY OF PARTICIPANTS

The following table gives the number of participants from each course (Project Lab and Engineering Comm) for each questionnaire survey and the application studies.

SUMMARY OF PARTICIPANTS

Course	Term	Engineering Task Preferences (%)	Project Performance Questionnaire (%)	Project Phases Questionnaire (%)	Dyadic Teams Participating In Appl. Studies (Total Teams Volunteering) [See Note]
Projects Lab.	Sum., 99	27 (58.7)	21 (45.7)	14 (30.4)	1 (4)
	Fall, 99	33 (31.4)	29 (27.6)	29 (27.6)	1 (8)
	Spr., 00	31 (27.4)	27 (23.9)	26 (23.0)	6
Engr. Comm. [a]	Fall, 99	51 (62)	51 (62)	[b]	[c]
	Spr., 00	50 (71)	50 (71)	[b]	[c]
Totals		192	178	69	3 (18)

[a] Engr. Comm, Fa1199, includes three sections, and Engr. Comm., Spring 00, includes two sections. Both Projects Lab and Engr Comm were given at The University of Texas at Austin, Dept. of Electrical and Computer Engineering.

[b] The projects in Projects Lab focused on technical performance and mirrored professional project activity. The projects, therefore, could be broken down consistently into the typical design phases. The projects in Engr Comm, on the other hand, were more variously defined, more pedagogical in nature, and more focused on communicative performance. For those reasons, only data from the Project Lab course was used for the Project Phases portion of the study.

[c] Application studies were restricted to dyadic teams in the Project Lab course.

Note: Eighteen teams volunteered to participate in the application studies and carried out their self-recordings of project discourse. Only three of the teams were selected for close analysis (see "Selecting Teams for Application Study" in the text). Some tapings were unusable for various mechanical reasons. For instance, the audiotape recorders had a voice actuation feature that frequently failed to pick up the voice of a quiet-spoken team member or a speaker some distance from the machine. Special instructions to the teams corrected this problem somewhat during the latter two semesters. In other cases, the speed of recording was such that intelligible playback, even on a transcription machine, was impossible. In addition, some teams were inattentive to the audiotape recorder and frequently conducted their discussions beyond the pickup range, or they simply forgot to turn the machine on.

APPENDIX C
ENGINEERING TASK PREFERENCE QUESTIONNAIRE

APPENDIX C
ENGINEERING TASK PREFERENCE QUESTIONNAIRE

As a professional engineer, you will have many ways to contribute to the operations of your company. Suppose you are beginning your job search now. What kind of job activities would you like to do for the firm that employs you?

Place an X in the blank that most nearly expresses how important the activity is to you at the present time.

1. To help my company build its reputation as a first-class organization.
   ____ Extremely important
   ____ Moderately important
   ____ Mildly important
   ____ Not important at all

[NOTE: IN THE FOLLOWING QUESTIONNAIRE ITEMS THE LIKERT SCALE HAS BEEN OMITTED.]

2. To work on projects that have a direct impact on the business success of the company.

3. To work on projects and systems that interest me technically.

4. To contribute to the business needs of the company.

5. To work on projects that I have originated.

6. To explore new and innovative technologies.

7. To learn my job well and be able to stick to what I know.

8. To work with others who are outstanding in their technical achievement.

9. To work under capable management.

10. To work on projects that incorporate advanced theories in my field.

11. To manage the work of others.

12. To prepare and deliver oral presentations to upper management.

13. To learn how the business is set up and run.

14. To learn administrative methods and procedures.

15. To become well-known outside my company as an authority in my field.

16. To receive patents on my technical ideas.

17. To publish articles in technical journals.

18. To present papers at professional societies.

19. To be evaluated only on my technical competency.

20. To have the respect of my colleagues on my technical abilities.

21. To have the respect of my colleagues on my managerial abilities.

22. To have the required command of English to present myself and my ideas well.

23. To work where requirements are clear.

24. To eventually start my own business.

APPENDIX D
PROJECT SATISFACTION QUESTIONNAIRE

APPENDIX D
PROJECT SATISFACTION QUESTIONNAIRE

Consider each of the following questions according to the totality of your experience in EE464. Please insert an X to indicate your level of agreement. [Note: A few questions are the same except for wording. This redundancy is necessary either for statistical purposes or for identifying the best phrasing for certain questions in the final study.]

1. I'm self-conscious about my speaking ability when my partner and I discuss engineering topics.
   ____Strongly agree.
   ____Mildly agree
   ____Mildly disagree
   ____Strongly disagree

[NOTE: TO SAVE SPACE AND AVOID REPETITION, THE LIKERT SCALE WILL NOT BE REPEAT IN THE FOLLOWING ITEMS.]

2. During our discussions, my partner and I often have to clarify an idea by drawing a sketch or diagram.

3. I feel I could have worked more effectively alone.

4. The longer we work together, the better my partner and I are able to communicate.

5. Because of communication difficulties with my partner, I feel I sometimes have to compromise on what I think is the best technical course of action for our project.

6. I usually communicate better (in English) with my fellow engineers than with my non-engineering friends and acquaintances.

7. My ability to express myself generally improves when my partner and I converse on a social level.

8. Generally, as the course continues, I find that my partner and I are gradually adjusting to each other's communication styles.

9. I feel that I have the technical competence to do the work in our project.

10. When I disagree with my partner on a technical issue, I sometimes go along with his or her opinion because I'm afraid I can't express my own opinion convincingly.

11. I prefer to concentrate on the technical or computational details of our project rather than the large theoretical concepts.

12. I am often confused by my partner's spoken English.

13. During our work, I frequently help my lab partner phrase his or her thoughts in clear English.

14. Our projects have offered me a real opportunity to show what I can do.

15. When we're meeting with our TA, I make a special effort to "talk like an engineer."

16. I sometimes feel that my technical knowledge is inadequate for the project I've been assigned.

17. I feel that my partner and I accomplish more as a team than either of us could accomplish alone.

18. My partner and I have similar experience and backgrounds, so that neither of us has to coach the other on technical concepts.

19. I feel that the quality of our work has depended largely on the ability of my partner and me to communicate well.

20. My partner and I seldom engage in general social discourse.

21. I usually let my lab partner speak for our project during discussions with our teaching assistant or adviser.

22. Our greatest communication challenge came at the beginning of our project, when we were trying to define our design problems.

23. There have been times when I felt my lab partner only pretended to understand what I was trying to say.

24. During our work together, I frequently help my lab partner put into words something he or she is attempting to express.

25. I speak much more fluently and freely when the TA is not present.

26. I tend to set the general direction and goals of our task and rely on my partner to supply the technical details.

27. Most of the time, my lab partner and I have difficulty communicating.

28. There are times when I only pretend to understand what my lab partner is saying.

29. I feel I have been able to participate fully in my team's decision-making.

30. I feel that at times my partner is confused by my spoken English.

31. Overall, I feel that my lab partner and I communicate smoothly and effectively.

32. Frequently, when we discuss the project with our TA, I find that I do most of the talking for our team.

33. I have confidence in my abilities to communicate as an engineer.

34. Sometimes my partner and I give up trying to understand each other on a point, and just go to another topic.

35. I sometimes know a better way to get a task done, but I'm unable to communicate my idea to my partner.

[36. I feel that my engineering project has been a significant social experience for me, as well as a professional one.] This question was added to let the participants end on a positive note, if they so desired.

THE END. THANK YOU VERY MUCH, AND GOOD LUCK.

APPENDIX E
SAMPLE CONSENT FORM FOR QUESTIONNAIRE RECIPIENTS

APPENDIX E
SAMPLE CONSENT FORM FOR QUESTIONNAIRE RECIPIENTS (PROJECT LAB)

CONSENT FORM: QUESTIONNAIRE PHASE
Communication Patterns in Collaborative Engineering Design

You are invited to participate in a study focusing on the general communication patterns between engineers working together during their EE464 project. My name is Mark Carpenter, and I am an assistant instructor in the Department of Electrical and Computer Engineering, as well as a graduate student at the University of Texas at Austin. I hope to learn more about the communication patterns, problems, and strategies of engineers while they are collaborating on complex design problems. Findings from this study will be useful to me in planning the curriculum for technical communication classes for engineers. In addition, I plan to present the study results at a national conference for educators in communication. You were selected as a possible participant because you are enrolled in EE464, in which you will work collaboratively with another student on an engineering design problem. All students enrolled in EE464 are being asked to participate.

If you decide to participate, I ask that you fill out the attached Background Information Form. It's short and should take only a few minutes. In addition, near the end of the semester, I will send you (by e-mail) a short questionnaire. This questionnaire will ask you simple questions about the ways you and your partner communicated with each other during the early stages of your EE464 project. This questionnaire, which is very important to this study, should take only about 5 minutes to complete.

And that's all there is to it. I realize that EE464 is an extremely important course for you, and this study is designed to take only a few minutes of your time.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Responses of participants will be reported only as averages or as aggregate data. No responses will be reported that can be identified as those of a given individual. Furthermore, your instructor or teaching assistant will not have access to any information collected in this study, nor will he or she be informed of such, except as aggregate data at the end of the semester.

Your decision whether or not to participate will not affect your future relations with the University of Texas at Austin. By signing this Consent Form, you are under no obligation to complete the questionnaire when you receive it. Your failure to complete and submit the questionnaire will be understood as a decision to discontinue your participation, or you may contact Mark Carpenter at Rm. 429, ENS Building (475-6329 or 474-2050) to report your wish to withdraw at any time.

You are making a decision whether or not to participate. Your signature indicates that you have read the information provided above and have decided to participate. You may withdraw at any time after signing this form, and you may decline to answer any question on the questionnaire.

If you have questions, contact Mark Carpenter at 475-6329 or 474-2050. My faculty advisor is ________________. You may keep a copy of this form. This original will be on file in Rm. 429, Engineering Sciences Building, University of Texas at Austin.

____________________________________ ________________________
SIGNATURE OF PARTICIPANT DATE

____________________________________ ________________________
SIGNATURE OF INVESTIGATOR DATE

APPENDIX E (CONT)
SAMPLE CONSENT FORM FOR APPLICATION STUDY PARTICIPANTS

<u>CONSENT FORM: APPLICATION STUDY PHASE</u>

Communication Patterns in Collaborative Engineering Design

You are invited to participate in a study of the communication patterns between engineers working together during their EE464 projects. My name is Mark Carpenter, and I am an assistant instructor in the Department of Electrical and Computer Engineering, as well as a graduate student at the University of Texas at Austin. Findings from this study will be useful to me in planning the curriculum for technical communication classes for engineers. In addition, I plan to present the study results at a national conference for educators in communication. You were selected as a possible participant because you are enrolled in EE464, in which you will work collaboratively with another student on an engineering design problem.

If both you and your partner decide to participate, I will ask that you conscientiously tape record your conversations during the first few weeks of your second project in EE464, specifically, from problem assignment to the completion of your project proposal. The conversations will include not only those between you and your partner, but also those between you and your teaching assistant or faculty advisor. I will supply you with audiotape recorders, batteries, and tape cassettes. Approximately once a week, you will give me the used audiotapes at my office (Rm. 429, Engineering Sciences Building). I will also ask for one or more short interviews, conducted at a mutually agreeable times, to resolve questions that arise during tape transcription and to obtain your assessment of the communication patterns that develop between you and your partner. When you turn in your project proposal and complete the interview(s), your participation ends, and you can return the recorders and unused audiotapes tome.

The tapes will be analyzed quantitatively for the types of utterances that characterize your discourse during engineering design work. Examples of data type are counts of conversation turntakings, topic initiations, and so on. Any direct quotations from your tapes will not be reported or published until after you have had the opportunity to review the material for accuracy. The sources of the reported or published quotations, moreover, will remain confidential. Your faculty advisor or teaching assistant will be aware that you are recording consultation sessions, but the researcher will not discuss these interviews with the advisor or teaching assistant until after the semester is over. At all times during the study, the audiotapes will be stored in a secure cabinet in ENS 429 and will be accessible only to the researcher. After the study is completed in 1999, the tapes will, on request, be returned to you, or retained in my personal possession until approximately July 1, 2001, at which time I will erase the tapes, unless you give me explicit permission to do otherwise.

In return for this work, you and your partner will receive $100 each. Any information that is obtained in connection with this study and that can be identified with you will remain confidential. Your decision whether or not to participate will not affect your future relations with the University of Texas at Austin or the Department of Electrical and Computer Engineering.

You are making a decision whether or not to participate. Your signature indicates that you have read the information provided above and have decided to participate. You are free to discontinue your participation at any time by notifying Mark Carpenter in writing at Rm. 429, Engineering Sciences Building.

If you have questions, please ask me, Mark Carpenter, at 475-6329. My faculty advisor is ______________. You may keep a copy of this form. This original will be on file in Rm. 429, Engineering Sciences Building, University of Texas at Austin.

______________________________	____________________
SIGNATURE OF PARTICIPANT	DATE
______________________________	____________________
SIGNATURE OF INVESTIGATOR	DATE

APPENDIX F
BACKGROUND INFORMATION FORM AND INVITATION

APPENDIX F
SAMPLE OF BACKGROUND INFORMATION FORM

The purpose of this Background Information Form is to assess the student makeup of EE464 Engineering Projects Laboratory for the Spring 2000 session. It is part of a study to characterize the communication patterns between engineers who are collaborating on engineering design projects (see attached Consent Form). Please take a few minutes to supply the following information. For questions, see Mark Carpenter, Rm. 429, Engineering Sciences Building, ph. 475-6329 or 474-2050. Thank you.

________________________________ ________________________

1. STUDENT'S NAME 2. E-MAIL ADDRESS

________________________________ ________________________

3. STUDENT'S NATIVE LANGUAGE 4. TELEPHONE

5.____ FEMALE ____ MALE 6. NO. SEMESTERS IN MAJOR ____

7. NUMBER OF MONTHS IN PAST YEAR THAT YOU HAVE COLLABORATED WITH OTHERS ON PROJECTS AT WORK OR IN SCHOOL. (CHECK ONE.)

____ less than 1 mo. ____ 1-2 mo. ____ 3-6 mo. ____ 7-12 mo.

8. NUMBER OF MONTHS IN PAST YEAR THAT YOU HAVE BEEN INVOLVED IN ENGINEERING DESIGN PROJECTS AT WORK OR IN SCHOOL. (CHECK ONE.)

____ less than 1 mo. ____ 1-2 mo. ____ 3-6 mo. ____ 7-12 mo.

9. A part of the study will examine actual (tape-recorded) discourse between partners in their engineering projects. I am currently seeking teams who would be willing to tape-record their problem-solving discourse during **the first few weeks of their second project** (from project assignment to proposal).

   If selected, you and your partner will be paid $xxx each simply for conscientiously tape-recording your conversations. Tapes, batteries, and recorders will be supplied. If your partner should agree, would you be willing to tape-record your communications with your partner and with your TA?

   Yes ____ No ____

   If "Yes," I will contact you and your partner by e-mail or phone in order to make arrangements.

10. IS ENGLISH YOUR NATIVE LANGUAGE? ____ YES ____ NO

[IF “NO” TO 10 ABOVE, PLEASE ANSWER ITEMS 10A THROUGH 10D.

10A WHAT IS YOUR NATIVE LANGUAGE _______________

10B YEARS IN THE U.S. __________ 10C TOEFL SCORE ________

10D ESTIMATE OF YOUR ENGLISH PROFICIENCY (Compared to a native speaker’s). Please check appropriate column for each level of language proficiency.

	Excellent	Good	Fair	Poor
Speaking	____	____	____	____
Writing	____	____	____	____
Reading	____	____	____	____
Listening	____	____	____	____

APPENDIX G
ENGINEERING TASK PREFERENCES QUESTIONNAIRE RESULTS

APPENDIX G
ENGINEERING TASK PREFERENCES QUESTIONNAIRE RESULTS

Questionnaire Item		Case 1		Case 2		Case 3		Overall Sample	
		Mike	Dan	Scott	Greg	Yass	Jack	Mean	SD
Q1	To help my company build its reputation as a first-class organization.	2.00	4.00	3.00	4.00	4.00	4.00	3.22	.7636
Q2	To work on projects that have a direct impact on the business success of the company.	3.00	4.00	3.00	4.00	3.00	4.00	3.47	.6616
Q3	To work on projects that interest me technically.	4.00	4.00	3.00	3.00	3.00	4.00	3.72	.5055
Q4	To contribute to the business needs of the company.	4.00	2.00	3.00	4.00	4.00	2.00	3.15	.7376
Q5	To work on projects that I have originated.	1.00	2.00	1.00	3.00	3.00	3.00	2.74	.8934
Q6	To explore new and innovative technologies.	2.00	4.00	2.00	3.00	4.00	3.00	3.42	.7612
Q7	To learn my job well and be able to stick to what I know.	2.00	4.00	2.00	3.00	2.00	1.00	2.95	.9032
Q8	To work with others who are outstanding in their technical achievement.	2.00	3.00	2.00	1.00	3.00	3.00	3.20	.7862
Q9	To work under capable management.	4.00	4.00	3.00	3.00	4.00	4.00	3.53	.6547
Q10	To work on projects that incorporate advanced theories in my field.	1.00	4.00	2.00	2.00	4.00	2.00	2.85	.8559
Q11	To manage the work of others.	1.00	3.00	3.00	2.00	2.00	1.00	2.54	.8905
Q12	To prepare and deliver oral presentations to upper management.	3.00	3.00	2.00	3.00	3.00	1.00	2.55	.9748
Q13	To learn how the business is set up and run.	2.00	4.00	1.00	3.00	2.00	2.00	3.1131	.9177
Q14	To earn the respect of my colleagues on my managerial abilities.	3.00	4.00	3.00	2.00	1.00	2.00	2.72	.9331
Q15	To become well-known outside my company as an authority in my field.	2.00	2.00	2.00	2.00	2.00	2.00	2.69	.9823
Q16	To receive patents on my technical ideas.	4.00	3.00	2.00	1.00	3.00	2.00	2.63	1.0146
Q17	To publish articles in technical journals.	3.00	3.00	1.00	1.00	1.00	1.00	2.16	.9415
Q18	To present papers at professional societies.	2.00	2.00	1.00	1.00	1.00	1.00	2.08	.9508
Q19	To be evaluated only on my technical competency.	1.00	3.00	2.00	3.00	3.00	1.00	2.23	.9193
Q20	To have the respect of my colleagues on my technical abilities.	4.00	4.00	3.00	3.00	2.00	2.00	3.34	.7183

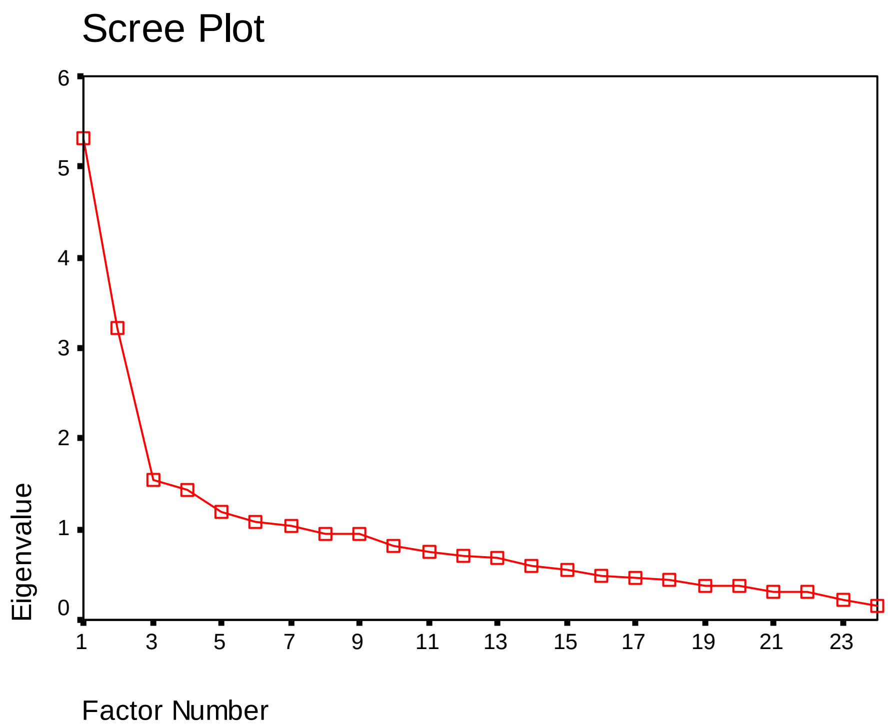
APPENDIX G (Cont)
ENGINEERING TASK PREFERENCES QUESTIONNAIRE RESULTS

Questionnaire Item		Case 1		Case 2		Case 3		Overall Sample	
		Mike	Dan	Scott	Greg	Yass	Jack	Mean	SD
Q21	To have the respect of my colleagues on my managerial ability.	4.00	3.00	3.00	4.00	1.00	2.00	3.04	.8706
Q22	To have the required command of English to present myself and my ideas well.	4.00	3.00	3.00	4.00	3.00	1.00	3.63	.6577
Q23	To work where requirements are clear.	3.00	4.00	4.00	3.00	4.00	1.00	3.17	.8228
Q24	To eventually start my own business.	1.00	3.00	2.00	4.00	1.00	4.00	2.58	.9622

APPENDIX H
ENGINEERING TASK PREFERENCE QUESTIONNAIRE
FACTOR ANALYSIS DATA

APPENDIX H
ENGINEERING TASK PREFERENCE QUESTIONNAIRE
FACTOR ANALYSIS DATA

SCREE PLOT



APPENDIX H (Cont)
ENGINEERING TASK PREFERENCES QUESTIONNAIRE

FACTOR ANALYSIS PATTERN MATRIX

[Pattern Matrix From Maximum Likelihood, Promax Rotation
3-Factor Extraction; Item Loadings>.30]

Pattern Matrix

	Factor		
	1	2	3
Q21	.802		
Q13	.709		
Q14	.690		
Q11	.677		
Q4	.594		
Q12	.578		
Q2	.407		
Q22	.363		
Q24	.361		
Q1	.317		
Q9	.308		
Q17		.943	
Q18		.879	
Q16		.560	
Q20		.353	
Q15		.345	
Q19		.308	
Q6			.757
Q10			.606
Q5			.534
Q3			.404
Q8			.371
Q7			.312
Q23			

Extraction Method: Maximum Likelihood. Rotation Method: Promax with Kaiser Normalization.
a Rotation converged in 5 iterations.

APPENDIX I
PROJECT SATISFACTION QUESTIONNAIRE RESULTS

APPENDIX I
PROJECT SATISFACTION QUESTIONNAIRE RESULTS

Questionnaire Item	Case 1		Case 2		Case 3		Overall Sample	
	Mike	Dan	Scott	Greg	Yas s	John	Mea n	SD
Q1 I'm self-conscious about my speaking ability when my partner and I discuss engineering topics.	1.00	1.00	2.00	1.00	3.00	1.00	2.11	1.09
Q2 During our discussions, my partner and I often have to clarify an idea by drawing a sketch or diagram.	3.00	4.00	4.00	4.00	4.00	3.00	2.55	0.98
Q3 I feel I could have worked more effectively alone.	1.00	1.00	1.00	2.00	3.00	4.00	2.00	0.97
Q4 The longer we work together, the better my partner and I are able to communicate.	3.00	4.00	3.00	4.00	4.00	2.00	3.30	0.79
Q5 Because of communication difficulties with my partner, I feel I sometimes have to compromise on what I think is the best technical course of action for our project.	1.00	3.00	3.00	2.00	2.00	2.00	2.12	1.00
Q6 I usually communicate better (in English) with my fellow engineers than with my non-engineering friends and acquaintances.	2.00	2.00	2.00	3.00	2.00	2.00	2.19	0.95
Q7 My ability to express myself generally improves when my partner and I converse on a social level.	3.00	2.00	3.00	3.00	2.00	1.00	2.99	0.86
Q8 Generally, as the course continues, I find that my partner and I are gradually adjusting to each other's communication style.	3.00	4.00	3.00	3.00	4.00	3.00	3.27	0.66
Q9 I feel that I have the technical competence to do the work in our project.	3.00	4.00	2.00	2.00	3.00	4.00	3.52	0.66
Q10 When I disagree with my partner on a technical issue, I sometimes go along with his or her opinion because I'm afraid I can't express my own opinion convincingly.	1.00	1.00	1.00	2.00	4.00	1.00	1.67	0.82
Q11 I prefer to concentrate on the technical or computational details of our project rather than the large theoretical concepts.	2.00	1.00	2.00	3.00	2.00	1.00	2.42	0.91
Q12 I am often confused by my partner's spoken English.	1.00	1.00	1.00	1.00	4.00	1.00	1.54	0.86
Q13 During our work, I frequently help my lab partner phrase his or her thoughts in clear English.	1.00	1.00	1.00	1.00	1.00	2.00	2.04	1.05

APPENDIX I (Continued)
PROJECT SATISFACTION QUESTIONNAIRE RESULTS

Questionnaire Item	Case 1		Case 2		Case 3		Overall Sample	
	Mike	Dan	Scott	Greg	Yass	John	Mean	SD
Q14 Our project has offered me a real opportunity to show what I can do.	4.00	4.00	3.00	3.00	3.00	3.00	3.00	0.86
Q15 When we're meeting with our TA, I make a special effort to "talk like an engineer."	3.00	1.00	1.00	3.00	2.00	2.00	2.45	0.92
Q16 I sometimes feel that my technical knowledge is inadequate for the project I've been assigned.	3.00	1.00	4.00	4.00	2.00	1.00	2.13	0.97
Q17 I feel that my partner and I accomplish more as a team than either of us could accomplish alone.	3.00	4.00	3.00	3.00	2.00	2.00	3.30	0.87
Q18 My partner and I have similar experience and backgrounds, so that neither of us has to coach the other on technical concepts.	2.00	2.00	2.00	2.00	1.00	1.00	2.51	0.99
Q19 I feel that the quality of our work has depended largely on the ability of my partner and me to communicate well.	4.00	4.00	1.00	4.00	3.00	1.00	3.12	0.89
Q20 My partner and I seldom engage in social discourse.	1.00	1.00	2.00	2.00	4.00	2.00	2.20	1.00
Q21 I usually let my lab partner speak for our project during discussions with our teaching assistant or adviser.	4.00	1.00	3.00	3.00	4.00	1.00	2.10	0.93
Q22 Our greatest communication challenge came at the beginning of our project, when we were trying to define our design problem.	4.00	1.00	4.00	4.00	4.00	3.00	2.94	1.03
Q23 There have been times when I felt my lab partner only pretended to understand what I was trying to say.	1.00	1.00	2.00	2.00	2.00	2.00	2.02	0.96
Q24 During our work together, I frequently help my lab partner put into words something he or she is attempting to express.	1.00	1.00	1.00	1.00	1.00	3.00	2.22	0.98
Q25 I speak much more fluently and freely when the TA is not present.	3.00	1.00	1.00	2.00	1.00	1.00	2.19	0.98
Q26 I tend to set the general direction and goals of our task and rely on my partner to supply the technical details.	3.00	1.00	1.00	3.00	2.00	1.00	1.53	0.79
Q27 Most of the time, my lab partner and I have difficulty communicating.	1.00	1.00	1.00	1.00	3.00	2.00	1.74	0.93
Q28 There are times when I only pretend to understand what my lab partner is saying.	3.00	1.00	1.00	2.00	4.00	1.00	3.60	0.64

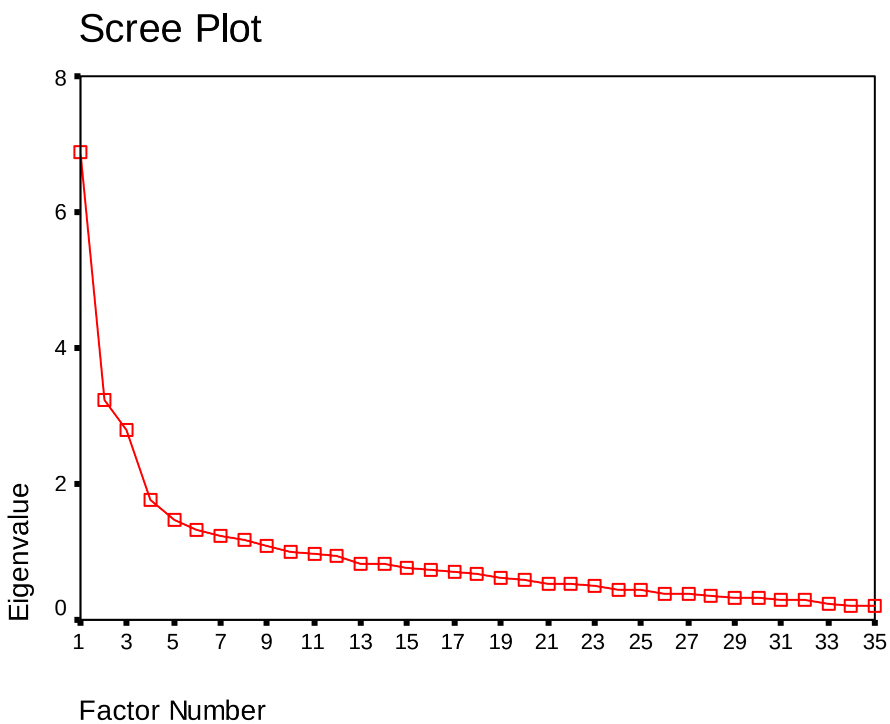
APPENDIX I (Continued)
PROJECT SATISFACTION QUESTIONNAIRE RESULTS

Questionnaire Item	Case 1		Case 2		Case 3		Overall Sample	
	Mike	Dan	Scott	Greg	Yass	John	Mean	SD
Q29 I feel I have been able to participate fully in my team's decision-making.	4.00	4.00	4.00	4.00	4.00	1.00	1.60	0.89
Q30 I feel that at times my partner is confused by my spoken English.	1.00	1.00	3.00	1.00	3.00	1.00	3.41	0.71
Q31 Overall, I feel that my lab partner and I communicate smoothly and effectively.	4.00	4.00	4.00	4.00	3.00	2.00	2.25	0.96
Q32 Frequently, when we discuss the project with our TA, I find that I do most of the talking.	1.00	1.00	2.00	2.00	1.00	4.00	3.44	0.60
Q33 I have confidence in my abilities to communicate as an engineer.	3.00	4.00	4.00	4.00	3.00	4.00	1.62	0.83
Q34 Sometimes my partner and I give up trying to understand each other on a point and just go to another topic.	1.00	1.00	2.00	3.00	4.00	2.00	1.70	0.85
Q35 I sometimes know a better way to get a task done, but I'm unable to communicate my idea to my partner.	1.00	1.00	1.00	2.00	3.00	3.00	1.53	0.79

APPENDIX J
PROJECT SATISFACTION QUESTIONNAIRE
FACTOR ANALYSIS

APPENDIX J
PROJECT SATISFACTION QUESTIONNAIRE
FACTOR ANALYSIS DATA

SCREE PLOT



APPENDIX J (CONT)
PROJECT SATISFACTION QUESTIONNAIRE
FACTOR ANALYSIS DATA

PATTERN MATRIX

Pattern Matrix

	Factor							
	1	2	3	4	5	6	7	8
Q27	.808							
Q34	.784							
Q12	.749							
Q28	.579							
Q10	.534							
Q31	-.506							
Q30	.498							
Q35	.434							
Q5	.411							
Q20	.373							
Q9		-.763						
Q16		.691						
Q21		.484						
Q26		.384						
Q14								
Q3			-.671					
Q17			.670					
Q19			.554					
Q32			-.419					
Q23								
Q18								
Q2				.686				
Q1				.635				
Q6				.527				
Q15				.391				
Q11								
Q22								
Q13					.865			
Q24					.831			
Q8						.624		
Q4						.543		
Q7						.444		
Q25							.864	
Q33							-.455	
Q29								.815

Extraction Method: Maximum Likelihood. Rotation Method: Promax with Kaiser Normalization.
a Rotation converged in 8 iterations.

APPENDIX K
ENGINEER PROFILES: ALL APPLICATION STUDY PARTICIPANTS

APPENDIX K
ENGINEER PROFILES: ALL APPLICATION STUDY PARTICIPANTS

Appl. Study Teams	Profiles	Task Preferences Profile			Project Satisfaction Profile							
		Mgmt Corp	Mi-cro-Tech	Hi-Pro	Team Com	Ind-Tech	Team-Tech	Com Awr	Com Asst	Com Impr	Com Conf	Partic
	Sam-plePro-file	*3.05*	*3.15*	*2.52*	*3.27*	*3.03*	*3.04*	*2.32*	*2.13*	*3.19*	*3.13*	*3.60*
1	Mike	2.82	2.00	2.67	3.80	2.00	3.75	2.25	1.00	3.00	2.50	4.00
	Dan	3.36	3.50	2.83	3.80	4.00	4.00	2.00	1.00	3.33	4.00	4.00
2	Sam	2.64	2.00	1.83	3.40	2.25	2.75	2.25	1.00	3.00	4.00	4.00
	Greg	3.36	2.50	1. 83	3.30	1.75	3.25	2.75	1.00	3.33	3.50	4.00
3	Yass	2.55	3.17	2.00	1.70	2.50	2.75	2.75	1.00	3.33	3.50	4.00
	Jack	2.45	2.67	1.50	3.20	4.00	1.25	2.00	2.50	2.00	4.00	1.00

BIBLIOGRAPHY

Ancona, D., & Caldwell, D. (1990). Information technology and work groups: The case of new product teams. In J. Galegher, R. Kraut & C. Egido (Eds.), *Intellectual teamwork: Social and technological foundations of cooperative work* (pp. 173-190). Hillsdale, NJ: Lawrence Erlbaum Associates.

Austin, J. (1975). *How to do things with words* (2nd ed.). Cambridge, MA: Harvard University.

Azmitia, M. (1988). Peer interaction and problem solving: When are two heads better than one? *Child Development, 59*, 87-96.

Azmitia, M., & Montgomery, R. (1993). Friendship, transactive dialogues, and the development of scientific reasoning. *Social Development, 2*(3), 202-221.

Baker, M. (1994). A model for negotiation in teaching-learning dialogues. *Artificial Intelligence in Education, 5*(2), 199-254.

Baker, M. (1998). *The function of argumentation dialogue in cooperative problem-solving.* Paper presented at the 4th International Conference on Argumentation (ISSA 98), Amsterdam.

Baker, M. (2002). Forms of cooperation in dyadic problem-solving. In P. Salembier & H. Benchekroun (Eds.), *Complexity*. Paris: Hermes.

Baker, M., Hansen, T., Joiner, R., & Traum, D. (1999). The role of grounding in collaborative learning tasks. In P. Dillenbourg (Ed.), *Collaborative learning: Cognitive and computational approaches* (pp. 31-63). Oxford: Pergamon.

Ball, L., Evans, J., & Dennis, I. (1994). Cognitive processes in engineering design: A longitudinal study. *Ergonomics, 37*(11), 1753-1786.

Barbieri, M., & Light, P. (1992). Interaction, gender, and performance on a computer-based problem-solving task. *Learning and Instruction, 2*, 199-213.

Barron, B. (2000). Achieving coordination in collaborative problem-solving groups. *The Journal of the Learning Sciences, 9*(4), 403-436.

Bell, N., Grossen, M., & Perret-Clermont, A.-N. (1985). Peer conflict and intellectual growth. In M. Berkowitz (Ed.), *Peer conflict and psychological growth* (pp. 41-54). San Francisco, CA: Jossey-Bass.

Berkowitz, M., & Gibbs, J. (1985). The process of moral conflict resolution and and moral development. In M. Berkowitz (Ed.), *Peer conflict and psychological growth*. San Francisco: Jossey Bass.

Bos, M. (1937). Experimental study of productive collaboration. *Acta Psychologia, 3*, 315-426.

Brown, A., & Palincsar, A. (1989). Guided, cooperative learning and individual knowledge acquisition. In L. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 393-451). Hillsdale, NJ: Lawrence Erlbaum Associates.

Bucciarelli, L. (1988). An ethnographic perspective on engineering design. *Design Studies, 9*(3), 159-168.

Bucciarelli, L. (1994). *Designing engineers*. Cambridge, MA: MIT Press.

Chi, M., Bassok, M., Lewis, M., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science, 13*, 145-182.

Chi, M., de Leeuw, N., Chiu, M., & LaVAncher, C. (1994). Eliciting self-explanations improves understanding. *Cogntive Science, 13*, 439-477.

Clark, H. (1996). *Using language*. New York: Cambridge University Press.

Clark, H., & Brennan, S. (1991). Grounding in communication. In L. Resnick, J. Levine & S. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 127-149). Hyattsville, MD: American Psychological Association.

Clark, H., & Schaefer, E. (1987). Collaborating on contributions to conversations. *Language and cognitive processes, 2*(1), 19-41.

Clark, H., & Wilkes-Gibb, D. (1986). Referring as a collaborative process. *Cognition, 22*, 1-39.

Cohen, E. (1994). Restructuring the classroom: Conditions for productive small groups. *Review of educational research, 64*(1), 1-35.

Cohen, E., Lotan, R., & Catanzarite, L. (1990). Treating status problems in the cooperative classroom. In S. Sharan (Ed.), *Cooperative learning: Theory and research* (pp. 203-230). New York: Praeger.

Cole, M., Engestrom, Y., & Vasquez, O. (1997). Introduction. In R. Calfee (Ed.), *Mind, Culture, and Activity: Seminal papers from the Laboratory of Comparative Human Cognition* (pp. 1-21). Cambridge, UK: Cambridge University Press.

Coleman, E. (1989). Using explanatory knowledge during collaborative problem solving in science. *Journal of Learning Sciences, 7*, 387-427.

Coleman, E. (1995). Learning by explaining: Fostering collaborative progressive discourse in science. In R. Beun, M. Baker & M. Reiner (Eds.), *Natural dialogue and interactive student modeling* (pp. 123-135). Berlin, Germany: Springer-Verlag.

Coleman, E., Brown, A., & Rivkin, I. (1997). The effect of instructional explanation on learning from science texts. *The Journal of the Learning Sciences, 6*, 347-365.

Crook, C. (1995). On resourcing a concern for collaboration within peer interactions. *Cognition and Instruction, 13*, 541-547.

Csikszentmihalyi, M. (1996). *Creativity: Flow and the psychology of discovery and invention*. New York: Harper-Collins.

Damon, W., & Phelps, E. (1989). Critical distinctions among three methods of peer education. *International Journal of Educational Psychology, 13*, 9-19.

Dembo, M., & McAuliffe, T. (1987). Effects of perceived ability and grade status on social interaction and influence in cooperative groups. *Journal of Educational Psychology, 79*, 415-423.

Dillenbourg, P. (1999a). What do you mean by collaborative learning? In P. Dillenbourg (Ed.), *Collaborative-learning: Cognitive and computational approaches* (pp. 1-19). Oxford: Elsevier.

Dillenbourg, P. (Ed.). (1999b). *Collaborative learning: Cognitive and computational approaches*. Oxford: Pergamon, Elsevier Science Ltd.

Dillenbourg, P., Baker, M., Blaye, A., & O'Malley, C. (1996). The evolution of research on collaborative learning. In E. Spada & P. Beiman (Eds.), *Learning in humans and machines: Towards an interdisciplinary learning science* (pp. 189-211). Oxford: Elsevier.

Dillenbourg, P., & Schneider, D. (1995). Collaborative learning and the Internet. On *[An electronic document available at http://tecfa.unige.ch/tecfa/research/CMC/colla/iccai95_14.html*.

Doise, W., & Mugny, W. (1984). *The social development of the intellect*. Oxford: Pergamon Press.

Dreyfus, A., Jungwirth, E., & Eliovitch, R. (1990). Applying the "cogntive conflict" strategy for conceptual change: Some implications, difficulties,and problems. *Science Education, 74*, 555-569.

Driver, R. (1987). Promoting conceptual change in classroom settings: The experience of the children's learning in science project. In J. Novak (Ed.), *Proceedings of the Second International Seminar on Misconeptions and Educational Strategies in Science and Mathematics*. Ithaca, NY: Cornell University.

Dunbar, K. (1998). Problem Solving. In W. Bechtel & G. Graham (Eds.), *A companion to Cognitive Science* (pp. 289-298). London: Blackwell.

Durling, R., & Schick, C. (1976). Concept attainment by pairs and individuals as a function of vocalization. *Journal of Educational Psychology, 68*, 83-91.

Engestrom, Y. (1987). *Learning by expanding: An activity-theoretical approach to developmental research*. Helsinki: Orienta-Konsultit.

Engestrom, Y. (1993). Developmental studies of of work as a testbench of activity theory. In S. Chaiklin & J. Lave (Eds.), *Understanding practice: Perspectives on activity and context* (pp. 64-103). Cambridge: Cambridge University Press.

Engestrom, Y., Engestrom, R., & Karkkainen, M. (1995). Polycontextuality and boundary crossing in expert cognition: Learning and problem solving in complex work activities. *Learning and Instruction, 5*, 319-336.

Engestrom, Y., Miettinen, R., & Punamaki, R.-L. (Eds.). (1999). *Perspectives on activity theory*. Cambridge, UK: Cambridge University Press.

Forman, E., & Cazden, C. (1985). Exploring Vygotskian perspectives in education: The cogntive value of peer interaction. In J. Wertsch (Ed.), *Culture, communication, and cognition: Vygotskian perspectives* (pp. 323-347). New York: Cambridge University Press.

Garfinkel, H. (1967). *Studies in ethnomethodology*. Englewood Cliffs, NJ: Prentice-Hall.

Gauvain, M., & Rogoff, B. (1989). Collaborative Problem Solving and Children's Planning Skills. *Developmental Psychology, 25*(1), 139-151.

Gibson, J. (1979). The ecological approach to visual perception. In. London: Houghton Mifflin.

Goel, V., & Pirolli, P. (1989). Motivating the notion of generic design within information processing theory: The design problem space. *Artificial Intelligence, 10*, 19-36.

Goel, V., & Pirolli, P. (1992). The structure of design problem spaces. *Cognitive Science, 16*(3), 395-429.

Goldberg, A. (2002). Collaborative software engineering. *Journal of Object Technology, 1*(1), 1-19.
Greeno, J., Collins, A., & Resnick, L. (1996). Cognition and learning. In D. Berliner & R. Calfee (Eds.), *Handbook of educational psychology* (pp. 15-46). New York: MacMillan.
Grice, H. (1975). Logic and conversation. In P. Cole & J. Morgan (Eds.), *Syntax and semantics* (Vol. Volume 3: Speech acts, pp. 225-242). New York: Seminar PRess.
Gunther, J., Frankenberger, E., & Auer, P. (1996). Investigation of individual and team design processes. In N. Cross, H. Christiaans & K. Dorst (Eds.), *Analysing design activity* (pp. 117-132). Chichester: Wiley Press.
Halverson, C. (1995). *Inside the cognitive workplace: New technology and air traffic control.* Unpublished PhD, University of California at San Diego, San Diego.
Hatano, G., & Inagaki, K. (1991). Sharing cognition through a collective comprehension activity. In L. Resnick, J. Levine & S. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 331-348). Washington, DC: American Pschological Association.
Heath, C., & Luff, P. (1991). *Collaborative activity and technological design: Task coordination in the London Underground Control Rooms.* Paper presented at the Second European Conference on Computer-Supported Cooperative Work, Kluwer, Dordrecht, the Netherlands.
Hertz-Lazarowitz, R. (1992). Understanding interactive behaviors: Looking at six mirrors of the classroom. In R. Hertz-Lazarowitz & N. Miller (Eds.), *Interaction in cooperative groups: Theoretical anatomy of group learning* (pp. 71-101). New York: Cambridge University Press.
Hertz-Lazarowitz, R., Kirkus, V., & Miller, N. (1992). Implications of current research on cooperative interaction for classroom application. In R. Hertz-Lazarowitz & N. Miller (Eds.), *Interaction in cooperative groups: Theoretical anatomy of group learning* (pp. 253-280). New York: Cambridge University Press.
Hinde, R. (1979). *Towards understanding relationships*. London: Academic Press.
Hogan, K., Nastasi, B., & Pressley, M. (2000). Discourse patterns and collaborative scientific reasoning in peer and teacher-guided discussions. *Cognition and Instruction, 17*(4), 379-432.
Hooper, S., & Hannafin, M. (1988). Cooperative CBI: The effects of heterogeneous versus homogeneous grouping on the learning of progressively complex concepts. *Journal of Educational Computing Research, 4*, 413-424.
Hooper, S., Ward, T., Hannafin, M., & Clark, H. (1989). Journal of Computer-Based Instruction. *16, 102-109*.
Hutchins, E. (2000). *Cognition in the wild*. Cambridge, MA: The MIT Press.
Hutchins, E., & Klausen, T. (1996). Distributed cognition in an airline cockpit. In D. Middleton & Y. Engestrom (Eds.), *Communication and cognition at work* (pp. 15-54). Cambridge, UK: Cambridge University Press.
Janis, I. (1982). *Groupthink* (2nd ed.). Boston: Houghton Mifflin.
Johnson, D., & Johnson, R. (1992). Positive interdependence: Key to effective cooperation. In R. Hertz-Lazarowitz & N. Miller (Eds.), *Interaction in cooperative*

groups: The theoretical anatomy of group learning (pp. 174-199). New York: Cambridge University Press.

Kuutti, K. (1996). Activity theory as a potential framework for human-computer interaction research. In B. Nardi (Ed.), *Context and consciousness: Activity theory and human-computer interaction* (pp. 17-44). Cambridge, MA: The MIT Press.

Lave, J. (1988). *Cognition in practice: Mind, mathematics, and culture in everyday life*. Cambridge, UK: Cambridge University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Lemke, J. (1990). *Talking science: Language, learning, and values*. Norwood, NJ: Ablex.

Leont'ev, A. (1981a). The problem of activity in psychology. In J. Wertsch (Ed.), *The concept of activity in Soviet psychology* (pp. 37-71). Armonk, NY: M.E. Sharpe, Inc.

Leont'ev, A. (1981b). *Problems of the development of the mind*. Moscow: Progress.

Lerner, G. H. (1987). *Collaborative turn sequences: Sentence construction and social action.* University of California, Irvine, CA.

Lincoln, Y., & Guba, E. (1985). *Naturalistic inquiry*. Beverly Hills, CA: Sage Productions.

Mandl, H., & Renkl, A. (1992). A plea for "more local" theories of cooperative learning. *Learning and Instruction, 2*, 281-285.

McIlwee, J., & Robinson, J. (1992). *Women in engineering: Gender, power, and workplace culture*. Albany, NY: SUNY.

Miyaki, N. (1986). Constructive interaction and the iterative process of understanding. *Cognitive Science, 10*, 151-177.

Nardi, B. (1996). Studying context: A comparison of activity theory, situated action, and distributed cognition. In B. Nardi (Ed.), *Context and consciousness: Activity theory and human-computer interaction* (pp. 69-102). Cambridge, MA: The MIT Press.

Newell, A. (1990). Unified theories of cognition. In *Cambridge, MA*. Harvard University Press.

Newell, A., & Simon, H. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice Hall.

Newman, D., Griffin, P., & Cole, M. (1989). *The construction zone: Working for cognitive change in the school*. Cambridge, UK: Cambridge University Press.

Nickerson, R. (1993). On the distribution of cognition: Some reflections. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 229-262). Cambridge, UK: Cambridge University Press.

Ormrod, J. (1999). *Human learning* (3rd ed.). Columbus, OH: Merrill.

Pea, R. (1993a). Learning scientific concepts through material and social activities: Conversational analysis meets conceptual change. *Educational Psychologist, 23*(3), 265-277.

Pea, R. (1993b). Practices of distributed intelligence and designs for education. In G. Saloman (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 47-87). Cambridge: Cambridge University Press.

Perkins, D. (1993). Person-plus: A distributed view of thinking and learning. In G. Saloman (Ed.), *Disributed cognitions: Psychological and educational considerations* (pp. 88-110). Cambridge: Cambridge University Press.

Perret-Clermont, A.-N., Perret, F.-F., & Bell, N. (1991). The social construction of meaning and cognitive activity in elementary school children. In L. Resnick, J. Levine & S. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 41-62). Hyattsville, MD: American Psychological Association.

Perry, M. (1997). *Distributed cognition and computer supported collaborative design: The organisation of work in construction engineering.* Unpublished Dissertation, Brunel University, London.

Piaget, J. (1932). *The moral judgment of the child* (M. Worden, Trans.). New York: Harcourt, Brace and World.

Piaget, J. (1970). *Science of education and the psychology of the child* (D. Coleman, Trans.). New York: Orion Press.

Piaget, J. (1977/1928). Logique genetique et sociologie. In *Etudes sociologiques* (pp. 203-239). Geneva, Switzerland: Librairie Droz.

Polya, G. (1957). *How to solve it: A new aspect of mathematical method*. Garden City, NJ: Doubleday.

Pugh, S. (1991). *Total design: Integrated methods for successful product engineering*. Reading, MA: Addison-Wesley Company.

Ragan, S. (1983). Alignment and conversational coherence. In R. Craig & K. Tracy (Eds.), *Conversational coherence: Form, structure, and strategy* (pp. 157-171). Beverly Hills, CA: Sage.

Reitman, W. (1964). Heuristic decision procedures, open constraints, and the structure of ill-defined problems. In M. Shelly & G. Bryan (Eds.), *Human judgements and optimality*. New York: Wiley and Sons.

Resnick, L. (1991). *Perspectives on socially shared cognition*. Hyattsville, MD: American Pschological Association.

Resnick, L., Salmon, M., Zeitz, C., Wathen, S., & Holowchak, M. (1993). Reasoning in conversation. *Cognition and Instruction, 11*, 347-364.

Rogers, Y. (1992). *Ghosts in the network: Distributed troubleshooting in a shared working environment.* Paper presented at the Computer-Supported Cooperative Work (CSCW) 92, New York.

Rogers, Y., & Ellis, J. (1994). Distributed cognition: An alternative framework for analysing and explaining collaborative working. *Journal of Information Technology, 9*(2), 119-128.

Rogers, Y., & Scaife, M. (1997). *Distributed cognition [Available online at http://www-sv.cict.fr/cotcos/pjs/T...edcog/DistCognitionpaperRogers.html]*

Rogoff, B. (1990). *Apprenticeship in thinking*. New York: Oxford University Press.

Rogoff, B. (1998). Cognition as a collaborative process. In W. Damon (Ed.), *Handbook of child psychology* (Vol. 2, pp. 679-744). New York: J. Wiley.

Rommetveit, R. (1985). Language acquisition as increasingly linguistic structuring of experience and symbolic behavior control. In J. Wertsch (Ed.), *Culture, communica-*

tion, and cognition: Vygotskian perspectives. Cambridge: Cambridge University Press.
Roschelle, J., & Teasley, S. (1991). The construction of shared knowledge in collaborative problem solving. In C. O'Malley (Ed.), *Computer-supported collaborative learning* (pp. 69-97). Berlin: Springer-Verlag.
Sacks, H., Schegloff, E., & Jefferson, G. (1974). A simplest systematics for the organization of turn-taking for conversation. *Language, 70*, 696-730.
Sacks, H., Schegloff, E., & Jefferson, G. (1978). A simplest systematics for the organization of turn-taking in conversation. In J. Schenkein (Ed.), *Studies in the organization of conversational interaction*. New York: Academic Press.
Saloman, G. (1993a). No distribution without individuals' cognition: A dynamic interactional view. In G. Saloman (Ed.), *Distributed cognitions: Psychological and educational considerations*. Cambridge: Cambridge University Press.
Saloman, G. (Ed.). (1993b). *Distributed cognitions: Psychological and educational considerations*. Cambridge, UK: Cambridge University Press.
Saloman, G., & Globerson, T. (1989). When teams do not function the way they ought to. *Journal of Educational Research, 13*, 89-99.
Schegloff, E. (1991). Conversational analysis and socially shared cognition. In L. Resnick (Ed.), *Perspectives on socially shared cognition* (pp. 151-171). Hyattsville, MD: American Psychological Association.
Schegloff, E., Jefferson, G., & Sacks, H. (1977). The preference of self-correction in the organization of repair in conversation. *Language, 53*, 361-382.
Schwartz, D. (1999). The productive agent that drives collaborative learning. In P. Dillenbourg (Ed.), *Collaborative learning: Cognitive and collaborative approaches* (pp. 197218). Oxford: Pergamon.
Simon, H. (1973). The structure of ill-structured problems. *Artificial Intelligence, 4*, 181-201.
Simon, H. (1981). *The sciences of the artificial* (2 ed.). Cambridge, MA: MIT Press.
Simon, H., & Lea, G. (1974). Problem solving and rule induction: A unified view. In L. Gregg (Ed.), *Knowledge and cognition*. Hillsdale, NJ: Erlbaum.
Slavin, R. (1983). When does cooperative learning increase student achievement? *Psychological Bulletin, 94*, 429-445.
Slavin, R. (1995). *Cooperative learning: Theory, research, and practice* (2nd ed.). Boston, MA: Allyn & Bacon.
Slavin, R. (1996). Research of the future: Research on cooperative learning and achievement: What we know, what we need to know. *Contemporary Educational Psychology, 21*, 43-69.
Steiner, I. (1972). *Group process and productivity*. New York: Academic Press.
Suchman, L. (1987). *Plans and situated actions: The problem of human-computer communication*. New York: Cambridge University Press.
Thagard, P. (1997). *How scientists explain disease*. Princeton, NJ: Princeton University Press.

Trowbridge, D. (1987). An investigation of groups working at the computer. In K. Berge, K. Pezdec & W. Banks (Eds.), *Applications of cognitive psychology: Problem solving, education, and computing*. Hillsdale, NJ: Lawrence Erlbaum Associates.
Tudge, J. (2000). Theory, method, and analysis in research on the relations between peer collaboration and cognitive development. *Journal of Experimental Education (electronic version at http://search.epnet.com/direct.asp?db=f5h&jn=JXE&scope=site), 69*(1), 98-113.
Tudge, J., & Rogoff, B. (1989). Peer influences on cognitive development: Piagetian and Vygotskian perspectives. In M. Bornstein & J. Bruner (Eds.), *Interaction in human development* (pp. 17-40). Hillsdale, NJ: Erlbaum.
Tudge, J., & Winterhoff, P. (1993). Vygotsky, Piaget, and Bandura: Perspectives on the relations between the social world and cognitive development. *Human Development, 36*, 61-81.
Verba, M., & Winnykamen, F. (1992). Expert-novice interactions: Influence of power status. *European Journal of Psychology of Education, 6*, 61-71.
Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.
Vygotsky, L. (1981). The genesis of higher mental functioning. In J. Wertsch (Ed.), *The concept of activity in Soviet psychology* (pp. 144-188). Armonk, NY: Sharpe.
Webb, N. (1980). A process-outcome analysis of learning in group and individual settings. *Educational Psychologist, 15*, 69-83.
Webb, N. (1984). Microcomputer learning in small groups: Cognitive requirements and group processes. *Journal of Educational Psychology, 13*, 21-40.
Webb, N. (1991). Task-related verbal interaction and mathematics learning in small groups. *Journal for Research in Mathematics Education, 22*, 366-389.
Webb, N., Ender, P., & Lewis, S. (1986). Problem-solving strategies and group processes in small groups learning computer prgramming. *American Educational Research Journal, 23*, 248-262.
Webb, N., & Palincsar, A. (1996). Group processes in the classroom. In D. Berliner & R. Calfee (Eds.), *Handbook of educational psychology* (pp. 841-873). New York: MacMillan.
Webb, N., Troper, J., & Fall, R. (1995). Constructive activity and learning in collaborative small groups. *Journal of Educational Psychology, 87*, 406-423.
Wenger, E. (1998). Communities of practice: Learning as a social system. *Systems Thinker, 9*(5).
Wertsch, J. (1981). *The concept of activity in Soviet psychology*. Armonk, NY: Sharpe.
Wertsch, J. (1984). The zone of proximal proximal development: Some conceptual issues. In B. Rogoff & J. Wertsch (Eds.), *Children's learning in the "zone of proximal development"*. San Francisco: Jossey-Bass.
Wertsch, J. (1985). *Vygotsky and the social formation of mind*. Cambridge, MA: Harvard University Press.
Wertsch, J. (1991a). A sociocultural approach to socially shared cognition. In L. Resnick, J. Levine & S. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 85-100). Hyattsville, MD: American Psychological Association.

Wertsch, J. (1991b). *Voices of the mind: A sociocultural approach to mediated action*. Cambridge, MA: Harvard University Press.

Wertsch, J., del Rio, P., & Alvarez, A. (1995). Sociocultural studies: History, action, and mediation. In J. Wertsch, P. del Rio & A. Alvarez (Eds.), *Sociocultural studies of mind* (pp. 1-34). New York: Cambridge University Press.

Wilkes-Gibb, D. (1986). *Collaborative processes of language use in conversations.* Stanford University, Stanford, CA.

Wood, D., Bruner, J., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Pyschology and Psychiatry, 17*, 89-100.

Yackel, E., Cobb, P., & Wood, T. (1991). Small-group interactions as a source of learning opportunities in second-grade mathematics. *Journal for Research in Mathematics Education, 22*, 390-408.

Zuboff, S. (1988). *In the age of the smart machine: The future of work and power*. New York: Basic Books.

Vita

Mark Allan Carpenter was born in 1943 in Ardmore, Oklahoma, and spent his childhood in Wichita Falls, Texas. His father is the late Frank Marques Carpenter, and his mother, Mary Lois Carpenter, currently resides in Whitesboro, Texas. After graduating from Wichita Falls Senior High School in 1961, Mark enrolled at The University of Texas at Austin and received his Bachelor of Arts degree in English in 1967. He joined the American space exploration efforts in 1969, and, working for a succession of large government contractors, he served as Science Editor for NASA's Apollo and Skylab Programs at the Johnson Space Center in Houston, Texas. He was among the first to examine lunar photographs returned by the Apollo lunar landing missions, and in fact he was a part of the staff that selected the first views for release to the public.

He left the space program in the mid-1970s to take the position of Proposal Coordinator for Brown and Root, Inc. in Houston, and several years later he joined El Paso Marine, the builder and operator of a fleet of ocean-going liquefied natural gas (LNG) carriers. In the early-1980s he was an independent contractor for a number of engineering firms before joining a 4-year project with Raytheon to help document the design, construction, and installation of an innovative deep-water offshore jacket design for Exxon. For two years afterwards he operated his own technical and commercial writing business in Houston until 1987, when he joined Intergraph, Inc. in Huntsville, Alabama. There he helped design and prepare users' documentation for a satellite-based mapping system.

During his years in Alabama, he attended the University of Alabama at Huntsville (UAH) and in 1993 received his Master of Arts in English, with certification by the

Teaching English to Speakers of Other Languages (TESOL) Society. In addition, he taught English as a Second Language (ESL) both at UAH and for the City of Huntsville. In 1994 he returned to the University of Texas at Austin to begin a doctoral program in Applied Linguistics. His goal was to study the discourse of engineers as they engage in design problem solving. As a graduate student at the University of Texas, he served as the Chief Editor of *Texas Papers in Foreign Language Education* (*TPFLE*), and since 1995 he has taught Engineering Communication for the Department of Electrical and Computer Engineering.

Mark has three children, Mark Allan Carpenter, Jr. of Houston, Texas; Stephen Michael Carpenter of Austin, Texas; and Theresa Love Stewart, currently residing in Germany with her husband Kim Stewart and son Ryan Marques Stewart.

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